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J. E. Leslie

J. E. Leslie

AN INTRODUCTION

TO

THE STUDY

OF

CHEMICAL PHILOSOPHY:

BEING A PREPARATORY VIEW OF

THE FORCES WHICH CONCUR TO THE PRODUCTION

OF

CHEMICAL PHENOMENA.

BY

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HONI SOIT QUI MAL Y PENSE
SANCTE ET SAPIENTER

LONDON:
JOHN W. PARKER, WEST STRAND.
M.DCCC.XXXIX.

LONDON
JOHN W. PARKER, ST. MARTIN'S LANE.

TO

MICHAEL FARADAY, D.C.L., F.R.S.,

FULLERIAN PROFESSOR OF CHEMISTRY IN THE ROYAL INSTITUTION,

&c. &c. &c.

MY DEAR FARADAY,

To you I dedicate this attempt to place amongst the elements of science the great discoveries with which you have adorned this prolific age. I know that you will not be displeased that I have thought them capable of being made the subject of familiar teaching.

The success of even this humble effort, should I not fail in my purpose, will be owing to you; for to your kind encouragement and ever ready explanations I owe the facilities which I have enjoyed in following you closely in your splendid career.

I must, however, be careful not to make you responsible for too much. You know that the consequence of repeating all your experiments has been that I have myself been led to experiment; and it may be that I have incorporated with your views speculations of my own of by no means so just a nature. My unaffected conviction is, that, in what I may differ from you, mine will be found to be the error, while yours must be the chief credit in what we may agree.

But whatever you may think of my philosophy, I have the happiness to feel assured that you will not lightly regard the sentiment of sincere affection with which I subscribe myself,

My dear Faraday,

Your faithful Friend,

J. FREDERIC DANIELL.

PREFACE.

THE origin of the following work was a desire to present to students of chemistry an elementary view of the discoveries of Dr. Faraday in Electrical Science. From the very first publication of his *Experimental Researches in Electricity*, I have felt that from them Chemical Philosophy will date one of its most splendid epochs; and perceiving, at the same time, that the results bear upon them the great impress of natural truths, namely, that they simplify while they extend our views, I have, from the first, availed myself of them in my instruction to my classes. I have enjoyed particular advantages in doing this from the kindness of the discoverer, for in every difficulty which arose, he has assisted me with his explanation and advice. At the same time, when consulted by my pupils upon the best mode of following up the oral instruction of lectures by the study of the subject in books, as they must do who intend to derive benefit from such instruction, I have been greatly at a loss to direct them.

The successive memoirs of an experimental philosopher, who, from time to time, communicates his views as they open out to him during the progress of his discoveries, must necessarily be better adapted to the study of the proficient, than to the instruction of the beginner; and long periods of time often elapse before the facts which they record find their places in general systems.

After some solicitation and much hesitation, I determined to make an effort to supply a want, which, I was perpetually reminded, was urgent, and which did not appear to be likely to be soon supplied from any other quarter.

Upon considering the best mode of carrying this design into execution, I became convinced that the great doctrine of "Definite Electro-chemical Action," and the laws of "Electrolysis," could not be simply and intelligibly stated without a preliminary notice, on the one hand, of the force of local affinity and the laws of definite, multiple, and equivalent proportions in chemical combination; and, on the other hand, of the force of electricity and the laws of electric charge and discharge in matter. A clear description, again, of the action of heterogeneous particles upon each other requires a distinction, which has not been sufficiently attended to, to be drawn between Heterogeneous Adhesion and Chemical

Affinity; and it is impossible now to treat of Electricity, without describing the phenomena of its constantly-associated force Magnetism.

Thus, I was gradually led to include in my plan such a preparatory view of the forces which may be said to concur to the production of chemical phenomena, as it is absolutely necessary to the student to master, who aspires to comprehend the Philosophy of Chemistry, or any thing beyond the mere manual operations of practical chemistry.

It has not been a part of my design to construct a system or manual of chemistry: several excellent works already exist, which render such an undertaking quite unnecessary; but I am not without hope that the following pages may be considered as a fit preparation for the study of such systems.

In executing my task, it has been my aim to lead the student by a more natural method,—that is, more gradually from the known to the unknown—than that which is generally adopted in our elementary books.

In short, if I shall be deemed to have failed in simplifying and facilitating the student's path to the comprehensive science of chemistry, I have failed in the sole object of my undertaking.

In such an elementary work, I have, of course, freely made use of the labours of others, and I regret that my limits have prevented me from mentioning, at all times, the names of those illustrious philosophers, either living or dead, to whom we are indebted for the observation of phenomena, and the fundamental inductions upon which the fabric of science rests. The history of the science of chemistry alone would fill a volume. I have, however, subjoined a list of those systematic works to whose assistance I have been most indebted.

I have judged it best in the arrangement of my work, to throw all the graphic illustrations of diagrams, or other figures, into the form of notes; and the explanation and etymology of scientific terms, of words of unfamiliar use, and of words to which it is desirable that the student should attach more definite ideas than are usually suggested by common parlance, I have given in a Glossary. The principal facts and reasoning of the text will thus be uninterrupted by extraneous matter, which, however important as a subsidiary means of explanation, might often confuse the steps of the induction; and those who are acquainted with the terms employed, will not be delayed by definitions which they do not need. It is, however, a caution which cannot be too strongly impressed upon every student, never to pass over a term which he does not understand, without seeking its explanation.

It only remains for me now, to acknowledge my obligations to my friends and colleagues, Professor Wheatstone and Dr. Todd, for their great kindness in undergoing the disagreeable labour of revising and correcting the proof sheets. They have thereby prevented many errors, which would otherwise have deformed the work.

THE FOLLOWING IS A LIST OF THE WORKS TO WHICH THE AUTHOR HAS BEEN PRINCIPALLY INDEBTED.

Experimental Researches in Electricity, by M. **Faraday**, D.C.L., published in the *Phil. Transactions*, from 1831 to 1839. Now in course of republication, in one volume, octavo.

Discourse on the Study of Natural Philosophy, by Sir J. F. W. **Herschel**, Bart.

History of the Inductive Sciences, by the Rev. **William Whewell**, B.D.

Lectures on Natural Philosophy, by **Thomas Young**, M.D.

A Manual of Chemistry, by **William Thomas Brande**.

Elements of Chemistry, by **Edward Turner**, M.D.

Traité de Chimie, par M. le **Baron L. J. Thenard**.

Elémens de Physique, par M. **Pouillet**.

Traité de L'Electricité et du Magnétisme, par M. **Becquerel**.

Treatises on Electricity, Magnetism, and Electro-Magnetism, in the *Library of Useful Knowledge*, by P. M. **Roget**, M.D.

Treatises on Optics and the Polarization of Light, in the *Library of Useful Knowledge*, by Sir **David Brewster**.

⁂ *The various Apparatus described in this work may be obtained of*
Mr. Newman, 122, *Regent Street.*

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INTRODUCTION TO CHEMISTRY.

§ 1. Experience, or the repeated evidence of our senses, and the irresistible persuasion of the mind, that "like causes will ever produce like effects," constitute the sound foundation of natural knowledge.

The convictions arising from these impressions have directed the intellect of man, in all ages and in all stations, to control the powers which have been imparted to the material universe to his own advantage; the maintenance of a bare existence in savage life being dependent upon them no less than the polished arts of civilized society. It is strange, however, to remark how long a time elapsed, even in a state of high intellectual culture, before it was discovered that the same principles which teach the mere child that fire will burn, that water will flow, and that a moving stone will inflict a blow, and to guide his conduct accordingly, would lead to that higher acquaintance with the powers of nature, which we distinguish by the title of *natural philosophy*. The powers of reason had been exercised with success upon abstract science for ages before the voice of Bacon proclaimed, and insisted earnestly upon, the advantages of extending experience by experiment, and of adopting the accurate observation of *phenomena*, as the only safe guide in *physical* investigations; but from the moment that this course was entered upon by the patient student of nature, natural science has advanced with a constantly accelerating progress, extending the power of mind over the forces pertaining to matter in a corresponding degree.

It deeply concerns the student who proposes to himself to enter upon any branch of such investigations, that he should have a right perception of these truths; that he should correctly distinguish the difference between abstract, and natural science, and clearly perceive the road along which his course must tend.

The contrast of these two great divisions of science has been forcibly represented by one of the living masters of both. "A clever man," Sir John Herschel has observed[*], "shut up alone, and allowed unlimited time, might reason out for himself all the truths of *mathematics*, by proceeding from those simple notions of space, and number, of which he cannot divest himself, without ceasing to think; but he could never tell, by any effort of reasoning, what would become of a lump of sugar, if immersed in water; or what impression would be produced on the eye by mixing the colours yellow and blue."

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[*] Herschel's *Discourse on Natural Philosophy*, p. 76.

§ 2. Experience, then, must be his guide; not the mere passive experience of observation, but the active experience of experiment: that is, he must not only carefully observe *phenomena* as they spontaneously present themselves to him in the ordinary course of nature, but he must purposely contrive and vary circumstances, in order that he may observe them.

To personal experience he must also add the well-attested experience of others; and the experience of past ages, as well as of the present; and as by following this course the generality of mankind attain to such an acquaintance with the properties of matter as ensures their comfortable existence, with which sensual object they are content; so he has but to persevere in the same, and it will lead him to that intimate knowledge of the order of creation, which constitutes science, and which is an object of ambition worthy of a rational creature.

The immediate wants of their nature early taught the human race to direct the agency of *heat* to their supply; and the accumulated experience of ages, widely diffused, has given the most unreflecting a command over that principle which strongly contrasts with the general ignorance concerning the no less general and powerful principle of *electricity*, the very existence of which could scarcely be said to have been recognised till within the last century. When well-directed observation shall have been brought to bear upon this all-pervading power, as upon the former, it is scarcely possible to indulge too sanguine hopes of the practical advantages which may flow from such extended knowledge. The forces of nature, indeed, are the powerful, but submissive, servants of man; and through their agency he has been endowed with a subordinate power of creation; but their respective actions have been limited by laws which cannot be transgressed; and in a knowledge of these limits consists the secret of their application.

§ 3. There are two great mistakes which are commonly committed by those who enter upon a systematic course of *physical* inquiry; and not only by those who are commencing, but by those who undertake to direct such studies: the first is, the neglecting to form a proper connexion with previously acquired knowledge,—the undervaluing the results of their ordinary experience as parts of the system,—as the first rounds of that intellectual ladder by which they aspire to scale the loftier heights of philosophy: and the second is, the substitution of names for things,—the vague acquirement of certain terms, certain forms of expression, instead of a real understanding of objects and principles to which they have been applied:—"terms of ignorance, and of superficial contemplation," as Lord Bacon calls them.

The process may be repulsive to the too common self-sufficiency of imperfect knowledge, but when invited to reflect and reason upon the simple observations of childhood (simple indeed, but not more easy than those which he will be called upon progressively to make), the student ought to feel no more offence than when in the outset of his *geometrical* studies he is referred to the axioms, or self-evident truths, that "things equal to the same are equal to one another," and "the whole is greater than its parts." It is from the known that he must ascend to the unknown, and it is all-important that he make his footing sure, and miss no step by the way.

§ 4. Something more, in fact, is necessary than the mere observation of phenomena; there must be a process of reflection upon the evidence of our senses:—the foundation must be crowned with a superstructure of thought and reason.

Professor Whewell, in his recent *History of the Inductive Sciences*, has accurately remarked *, that "two things are requisite to the formation of science;—facts and ideas; observation of things *without*, and an *inward* effort of thought; or, in other words, *sense* and *reason*. Neither of these elements, by itself, can constitute substantial general knowledge." It is owing to a defect in this mental process that different arts have often attained to a considerable degree of perfection long before they could be said to form parts of a general structure of science. The chemical arts of glass-making, metallurgy, dyeing, and many others, were known to the ancient Egyptians, who, probably, were utterly ignorant of the principles of chemical philosophy.

The aim of the student then must be not only to obtain distinct facts, but clear ideas of the connexion of those facts. Now it is by processes of thought, and operations of mind, which are quite familiar, that the observations of experience and experiment are connected into the order and structure of science; for the principles of natural philosophy are but the principles of common sense.

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* WHEWELL'S *History of the Inductive Sciences*, Vol. i. p. 6.

In the ordinary occurrences of life we are struck with some appearances,—some phenomena we may call them,—which are out of the ordinary course of our experience: the mind immediately suggests the familiar inquiry, "What can these be?" We form a conjecture, and we try whether the supposition will include all the circumstances of the case; we reject it, and we guess again; and we proceed in this tentative method till our reason is satisfied that we have taken a right view of the subject. The formal course of philosophy differs not from this.

Amongst a variety of facts, or *phenomena*, collected together as having some general resemblance or connexion with each other, some *governing principle* is sought, which may apply successfully to the explanation of all their varieties;—suppositions, guesses, or *hypotheses*, are first attempted; some with greater, some with less extent, but all, perhaps, without success; each after each failing in the solution, for want of generality and comprehensiveness; till at length, after infinite labour on the part of the inquirer, the LAW is evolved; or a governing principle which combines all together in one comprehensive view, or *theory*. When by this simple, but laborious process of *induction*, the mind has once been *led up to* such *laws of nature*, they are found to be distinguished by their exceeding simplicity both of form and essence.

The full force and range of their application are, however, only manifested when, subsequently to their discovery by this *inductive process*, they are employed in the converse process of *deduction*, to resolve the various cases which were originally proposed to be determined, and are found to include under their government not only these but a host of others, which were not contemplated in the first investigation. It is then that the most ignorant and simple-minded are capable of understanding what appears to be almost self-evident; and the multitude of such governing principles, so established and registered in her archives, constitutes the great advantage of modern science.

§ 5. In framing the *hypotheses*, or suppositions which commonly precede the discovery of the real laws and true theory of phenomena, there is one useful guide which is so often referred to as to render it expedient to explain its nature and appellation, and that is *analogy*, or similitude. Design soon becomes apparent in the order of creation; and this design, as far as our limited faculties can trace it, is uniform; and in the system of the universe every part is doubtless proportioned to the whole. No intelligence but that of OMNISCIENCE can comprehend the plan—the *theory* of the universe: but, from the plan of such small portions as have been mastered, we are often enabled, successfully, to anticipate the order of other portions; and thus to obtain a guide to experiment, to which the ultimate appeal must always be made. *Analogy*, therefore, may serve to suggest and limit *hypotheses;* and of such conditional speculations we have the highest authority for saying, that "a facility in framing them, if attended with an equal facility in laying them aside when they have served their turn, is one of the most valuable qualities a philosopher can possess*."

§ 6. Now, to apply these few plain principles to our present purpose:—With regard to precision of terms, the mere enunciation of the object of the following pages will afford us an opportunity of exemplifying and enforcing our meaning; it is an inquiry into THE FORCES OR POWERS OF MATTER. Let us endeavour to ascertain and define the meaning of the expressions MATTER and FORCE: the words are of common occurrence; but have we that distinct notion of them, those clear ideas concerning their import, which it behoves us to have, in the strict and accurate investigation upon which we are about to enter?

§ 7. Our first knowledge of *matter* is derived from our *touch*: a consciousness of resistance in surrounding objects to this sense with which our bodies have been endowed, impresses us with a conviction of their *substance*,—of their *extension*,—of their *impenetrability*,—of their power, that is, to exclude every thing of the same kind from being in the same place. This tactile property is possessed by different parts of the skin, in very different degrees; and some parts of the body, from their peculiar organization, are capable of much more delicate impressions from objects with which they may be placed in contact than others. With regard to extension, for instance, it appears, from the experiments of Weber, that the tips of the fingers, or the tongue, are capable of appreciating the distance between the points of a pair of compasses which are only one line apart; while the arm or the thigh would confound the two impressions together, even at the distance of thirty lines. Those whose touch has been educated by practice can rule, by their feeling, fine linear divisions which are totally inappreciable to the most experienced eye.

Different degrees of resistance may even inform us of the different states in which matter exists: a touch will satisfy us that the parts of some bodies are immoveable amongst each other; that the particles of others are moveable with little resistance; while the passing breeze of air will convince us that matter exists in a form which yields to the lightest breath. A little reflection upon our sensations may thus establish a difference between *solid*, *liquid*, and *aëriform* matter. Experience, again, and the oft-repeated experiments, it may be said, of infancy, teach us to combine observations of touch with those of sight and hearing; and thus we learn to substitute the indications of one sense for those of another, and to judge of distant forms of matter.

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* HERSCHEL'S *Discourse*.

With regard to the ultimate constitution of matter, we cannot hope to attain to a clearer conception than that which presented itself to the comprehensive, but humble, mind of Newton; and that transcendent philosopher has thus embodied the result of his patient investigations:—

"It seems probable to me that GOD, in the beginning, formed MATTER in solid, massy, hard, impenetrable, moveable particles, of such sizes and figures, and with such other properties, and in such proportion to space, as most conduced to the end for which He formed them; and that those primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces; no ordinary power being able to divide what GOD himself made one in the first creation."

§ 8. It is, however, no less necessary to test the accuracy of our notions derived from common observation and the first impression of our senses, than to guard against the careless adoption of ill-understood generalizations of the results of experiment in our after progress; and we must be particularly careful to correct the prejudices which are but too apt to infect the mind from this first fountain of our knowledge. With regard to the absolute hardness, for instance, of the ultimate atoms of all kinds of matter:—from the smooth flowing of water, and the gentle breathing of the air, we derive a notion of softness which we can scarcely separate from the constitution of their ultimate particles; but if we take a portion of water in a glass tube, which has been carefully freed from air by boiling, and afterwards hermetically sealed, we shall find, upon agitating it, that the particles strike one another with a ringing sound, quite undistinguishable from that derived from the collision of metals. Such a little apparatus is commonly made, and goes by the name of the *water-hammer*. So with regard to aëriform matter; a mixture of airs may be confined in a mere film of water, which exploding at a lighted taper, will allow the particles of the atmosphere to rush together so suddenly as to produce a loud report, the result of the collision of aëriform atoms.

Again, Newton has drawn a marked distinction between the solidity of "primitive particles" and that of the bodies compounded of them; asserting that the latter are *porous:* and yet we seem but to be giving fair credit to the testimony of our senses, in believing that the particles of a solid metal must be in close contact. A little reflection again may correct this prejudice. Many metals may have their density increased; *i. e.*, their particles approximated, by mere hammering or pressure; but to this there is a limit: all solids may have their particles approximated by cold, and to this no limit has been yet ascertained. Particles which admit of such nearer approach to each other cannot of course be in close contact; a mass, or an assemblage of such, must be porous.

§ 9. If we are liable to such errors of judgment, with regard to matters of direct observation, how careful ought we to be, and how diffident, in embodying notions of things which are wholly beyond the cognizance of our senses;—as of the sizes, forms, or weights of the "primitive particles," or *atoms*, of matter. We can carry the palpable division of some substances to an almost inconceivable extent, but we have no reason to suppose that we thereby even approximate to their ultimate *atomic* resolution.

A gallon of water weighs 70,000 grains; one-tenth of a grain of green vitriol does not contain quite one-fiftieth part of a grain of iron; if we dissolve this quantity of the salt in the water, its diffusion throughout its whole mass may be rendered perfectly visible by the addition of a little tincture of the gall-nut; *i. e.*, it may be proved to the eye that each grain of water contains the seventy thousandth part of the fiftieth of a grain of iron; a quantity far too minute to be ascertained by the most delicate instruments, and of which the imagination itself cannot possibly frame an accurate conception: and yet we dare not assert that this inconceivably minute quantity bears any assignable proportion to the weight of a primitive particle.

§ 10. But, to proceed: we are familiar with matter in two states; viz.—at rest; or undergoing a change of position in space: but no particle of matter, nor assemblage, nor compound of particles of matter, possesses within itself a power of changing its existing state of motion or rest; a passive quality which is generally designated by the *term* INERTIA. This term, however, appears to have been not very happily chosen; inasmuch as it might be taken to designate inactivity with regard to other bodies; which if we were to admit, we should deny that inherent activity by which it is probable that every particle of matter is capable of acting upon every other particle in the universe.

When we are told that a body at rest would for ever remain quiescent, unless it were to receive an impulse from some extraneous power, the mind at once assents to the proposition; it seems to agree with the results of our experience; the bodies which surround us move not until some power from without sets them in motion: but it requires some reflection in those who, for the first time, consider the subject, to perceive that bodies in motion would for ever continue to move unless they were stopped by some exterior power. Common and careless observation seems to contradict this part of the proposition: we know of no motion on the surface of the earth but what comes to an end, unless extraneous power be applied not only to produce but to maintain it. This prejudice will, however, be corrected by the observation, that all such moving bodies meet with resistance from counteracting forces; and that the heavenly bodies, the only examples with which we are acquainted of unresisted motion, continue constant in their courses. Moreover, we are not without familiar instances of this tendency to a persistence in a state of motion. If we suddenly check motion, in an open vessel filled with a liquid, the rigidity of all the parts of the solid mass brings them simultaneously to a state of rest; but the mobility of the liquid particles of the combination allows of their continuing in motion in their original direction, and the liquid is spilled. The careless setting down of a pail of water, or of a cup of tea, may thus, with proper reflection, illustrate an important principle.

§ 11. Now every particle of matter which we see around us is under the influence of several FORCES exerted upon it both by distant and by adjacent particles; and upon which it acts in return: for the *action* of one body upon another is always accompanied by a *reaction* of the latter upon the former, of the same intensity in the opposite direction. To these forces the motions which we observe in some bodies are owing, and upon their balance the apparent state of rest in others is dependent: it is, therefore, of the first importance that we should form as accurate a notion as possible of the meaning of the general term FORCE. The following analysis of the subject, by Sir John Herschel, clearly refers the origin of the idea to the consciousness of each individual [*]:—

"We are conscious of a power to move our own limbs, and, by their intervention, other bodies; and this effect is the result of a certain inexplicable process which we are aware of, by which we exert *force;* and even when such exertion produces no visible effect (as when we press our two hands violently together, so as just to oppose each other's effort), we still perceive, by the fatigue and exhaustion, and by the impossibility of maintaining the effort long, that something is going on within us, of which the mind is the agent, and the will the determining cause." In the case of force exerted by the right hand, and met by an equal force from the left, the two acting in opposite directions exactly neutralize each other, and no motion ensues; the effect is *pressure;* they exactly balance one another, and may be said to be in *equilibrio.* We recognise a similar power of generating force in other animals by opposition to our own, and as the proximate seat of it is in the muscles, we denominate it *muscular* or *animal force.* This force may be communicated to inanimate matter, as when we project a stone from the hand; and that a body thus set in motion carries force with it, we may feel by arresting it in its course. Thus, in stopping a ball at cricket, we feel a shock, and the bones of the hand might even be fractured by the blow if it did not at first yield a little to its course. It may be concentrated in the same mass by continued action, as when a stone, which when cast from the hand will inflict a comparatively slight injury, is continuously acted upon by the same arm, by the intermedium of a sling, it will at length be projected with an intensity of action capable ot producing very violent effects. We thus learn to regard motion in matter, however produced, as the effect, and indication of force.

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[*] HERSCHEL'S *Discourse*, p. 86.

Velocity of motion may, when the mass remains tho same, be taken as a measure of *mechanical force* (as force thus transferred to moving masses of matter is called), and by multiplying the mass of a body by the square of its velocity we, in all cases, learn its *momentum*, or the quantity of force which it is capable of exerting upon other bodies opposed to it. The investigation of the laws of motion constitutes the province of DYNAMICS.

§ 12. This force which we can exert and communicate at will, and which can be generated by all animal bodies, we may soon become sensible may be opposed by other forces appertaining to inanimate matter. For example:—in lifting a lump of iron, or lead, or stone, from the ground, we are conscious of the same kind of opposition, and consequent exertion, as when we violently press one hand against the other; and whatever opposes force must be force. If the force which we apply be greater than the opposing force, which we familiarly denominate *weight*, the mass is raised; but we may so adjust the two that they may be *in equilibrio*, and then no motion will be perceptible; but we shall feel its *pressure*, and, if the mass be considerable, we shall not long be able to maintain the balance, from exhaustion and fatigue, and the mass will fall to the ground.

Again, by pressing with the arm upon a strong spring, or in drawing a bow, we feel another opposing power, which we denominate ELASTICITY. At the first impression motion may be produced, because muscular force may have the advantage, but we shall soon become conscious of a gradually increasing opposition, which our utmost exertion will not be able to overcome; our highest degree of force will be balanced; fatigue on our part will put an end to the contest, and the elastic body will return to its former state. If the opposition be suddenly withdrawn, and the bow be allowed to act continuously in its return upon a body which is free to obey the impulse, the bolt or the arrow will have a projectile force communicated to it of considerable intensity, as in the case of the stone from the sling.

§ 13. The very same effect may be produced upon the spring or bow by the action of the weight, as by the power of the arm; and if we were to place the mass of iron upon the former, or suspend it from the latter, the heavy body would be supported, and the elastic body would be bent. Weight may thus be opposed to elasticity, and at a certain point they will balance each other: at this point no motion or visible effect will be produced; but the two forces will not on this account cease to act any more than in the case of the opposite pressure of the two hands; they will exert pressure upon each other. Each of these forces having been separately estimated by our exertion and consciousness of muscular force, when opposed to them, we cannot resist the direct evidence of our senses, that "matter is thus capable of exerting upon matter the same kind of effort as that which we appreciate from a mental impression *."

There are several varieties of such force, all of which may either *mediately* or *immediately* be referred to the standard of our own exertions. Some of these cause masses of matter to approach, and others to recede from each other; the former are classed together under the name of ATTRACTION, the latter under that of REPULSION. The laws of these motions, and of the equilibrium of these forces, the intellect of man has been able to develope; but the origin of the forces themselves, though clearly perceived to be various, appears to be beyond his comprehension, even when that origin is in his own will. We cannot, at least, refer them to any secondary cause, and we must be content to know that they are powers conferred upon matter by the will of the CREATOR, for the maintenance of the order of his creation. Thus much the intellect of a child can comprehend, and to nothing more did that of a Newton attain. The effort which we feel that a mass of iron makes to fall to the ground, is due to an attractive force between it and the earth, which we denominate GRAVITY, and is an universal power of nature; that which we feel the spring make to recover its first position when we press upon it with the hand, is due to the repulsive force of ELASTICITY, and is possessed in very different degrees by different kinds of matter.

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* HERSCHEL'S *Discourse.*

Before we proceed to inquire into the laws which limit the action of these forces, it will be well to indicate certain other varieties both of *repulsion* and *attraction*, which will come within the scope of our inquiry.

§ 14. It was observed by the ancients, and the fact is mentioned by Theophrastus, that when a piece of amber is rubbed, it acquires the property of attracting light bodies. The Greek term for amber being *electron*, the unknown cause of this phenomenon has been called ELECTRICITY. It was not till the commencement of the seventeenth century that the same property was found to be conferred, by friction, on various other bodies, as glass, sealing-wax, sulphur, &c.; and later still, that any two dissimilar substances, when rubbed together, with proper precautions, are capable of exerting the same attractive force. Further observation has shown, that after bodies have been thus attracted to the rubbed surface, they will be repelled from it by an equal but opposite force; and the *phenomena* will be presented to us in a striking light if we suspend a feather from a piece of silk, and approximate to it a tube of glass, which has been rubbed with a silk handkerchief; the feather will be attracted to the tube from a considerable distance, and after attaching itself to it will fly off, and cannot be made again to approach it. Both this attraction and repulsion will overcome the force of gravitation in the feather, and by its opposition we can estimate the amount of either.

§ 15. Again, there is an ore of iron which is common in Sweden, which has received the name of *loadstone*, from the property which it possesses of pointing, when freely suspended, to the polar star, or *load-star*, as it was formerly called; it has been known from remote antiquity to possess the property of attracting small pieces of iron; it is said to have abounded in Magnesia, a province of Lydia, and is mentioned by Pliny, under the name of *magnes*, hence the property derived the name of MAGNETISM. It is capable of being communicated to bars of steel by friction, which are also called *magnets*. If we take two bars so prepared, and balance one of them upon a pivot, we may again have the opposite forces of attraction and repulsion exemplified from this new source; for upon approximating one end of one magnet to a certain end of the other, which is free to rotate, they will approach each other with considerable energy; if the other end be presented to it, they will separate with equal velocity. This attraction we can feel and estimate by the muscular force which we must exert to pull away a piece of iron which is under its influence. Artificial magnets, as well as the load-stone, when freely suspended, take up a definite position with regard to the *poles* of the earth, or the extremities of any other magnet: hence this property has been termed *polarity*; and forces which are conceived to act with equal intensity in opposite directions at the extremities of the axes of molecules, or masses of matter, are denominated *polar forces*.

§ 16. The forces which we have thus designated may be distinguished as EXTERNAL FORCES, for they act upon masses of matter at sensible distances: there are others which act only upon its constituent molecules, and at insensible distances, and may be called INTERNAL OF MOLECULAR FORCES.

§ 17. The first, and most general of these, is *homogeneous attraction*, or *cohesion*. If we take two *masses* of lead, on which two perfectly smooth surfaces have been cut,—and a cloven bullet will answer the purposes of illustration,—and bring these planes in contact, we shall find that they cohere, or attract each other with a force which we can appreciate by a muscular effort to separate them: or by opposing to them the gravitation or weight of another body, for we may suspend a heavy substance to them without forcing them asunder. In the same way, two pieces of plate-glass cohere strongly together when brought into contact, by their polished faces. It has often happened in manufactories of this article, that the plates, which after receiving their last polish are placed in cases where they are arranged like books in a book-case, a little inclining upon each other, have been found to have contracted so strong a *cohesion* as not to be separable without a fracture; and sometimes three or four plates have thus become so incorporated as to bear working together, and cutting with a diamond, like a single plate. Some specimens, which were selected from the manufacture of St. Gobin, were found to be thus united no less intimately than if they had been fused together; and when a violent degree of force was applied to make them slide from each other, the experimenter was surprised to find that the substance of the glass was actually torn, so that the surface of one was covered with large flakes detached from the substance of the other.

Another example of this force is afforded by the running together of two globules of mercury, or two drops of water; the moment they appear to touch each other they coalesce, and become one. One of the most striking illustrations of homogeneous attraction is afforded by sifting some finely powdered resin upon a plate, and carefully scattering a few drops of water upon it; each of these will assume an almost perfect globular form, from the equal action of this force, in all directions from the centre, in obedience to which the particles of each mass are free to move; these small globes may be made to roll about in all directions, like solid shot, by inclining the plate. When made gently to touch each other, they still continue separate, the liquid particles being defended from actual contact by the light dust with which they are powdered; but when by greater violence this is dispersed, they immediately run together.

This is the force which connects the particles of bodies together in the solid form with greater or less energy, and which still prevails in liquids, though reduced to a less amount by an opposing force which we must presently indicate. We have seen from our experimental illustrations, how gravity, or muscular force, may be made to act in opposition to it, and the two may be combined to such a degree of intensity by the continuous action, for instance, of the sledge-hammer, that the cohesion of the hardest solid may be obliged to yield.

And here it may be remarked, that *time* is an important element in the action of force. When a mass of matter moving with a certain *momentum* strikes against a substance whose cohesion is insufficient to resist the force which it conveys, the fracture of the latter is the consequence, and the momentum of the former may be destroyed; but if a greater velocity be given to the mass, it may pass through the opposing substance with little comparative injury, and still continue to move. Thus a leaden bullet projected from the hand may demolish a plate of glass, while the same bullet impelled from a gun will pass through the plate, and pierce it with a small hole, without destroying the cohesion in any other part. In the practice of artillery, where it is required to batter down walls, or the sides of a ship, the charge of gunpowder is so regulated as that the projectile may not be carried through the object aimed at; as in that case the time of its passage is not sufficient for the transfer of the force from the moving body.

§ 18. Elasticity also may be made to act against cohesion; and a most beautiful instance of the *equilibrium* of these two forces is presented to us in the common schoolboy's plaything, called a Rupert's drop. This is a drop of glass suddenly solidified by dropping it into water; its cohesion is very considerable, as we may ascertain by the force which would be required to crush it; it will bear the pressure of half a hundred weight without injury. Glass is also a body endued with a high degree of elasticity, which is greatly increased by heat. When the exterior molecules are suddenly cooled they contract, and violently compress the still heated interior particles. That these retain their state of tension, and strive energetically to recover from it, even after they are cool, is proved experimentally. If we grasp the drop in one hand, and with the other break off the point, or merely scratch the surface, we diminish the force of cohesion, and the elasticity assumes the ascendency, breaking the mass to an almost impalpable powder, and giving a violent shock to the hand which grasps it. By holding it under water, in a stout glass bottle, or other vessel, the effect is rendered still more striking; for upon scratching the surface with a file, not only is the drop, but the containing vessel, shivered into a thousand fragments.

§ 19. But the real, and, but for one remarkable exception, *universal* antagonist of cohesion, is the repulsive force of HEAT: and of the meaning, again, of this term, our consciousness will afford the best explanation. The sensations of the most ignorant teach them to apply a meaning to the terms *hot* and *cold*, which the most philosophic definition would not at all elucidate. Common experience proves to us that the unknown cause of these sensations is an agent of the most powerful and active kind: we find it continually employed both in the processes of nature and the arts; we recognise it as destroying some substances, melting others, rendering others luminous, and converting others into vapour. The hidden cause of all these effects we term *heat*, as well as the sensation which it produces upon our organs. Our ignorance occasions this confusion of language, and we only attempt to disguise that ignorance when we substitute the term *caloric* for the mysterious cause, and confine the term heat to the sensation produced.

§ 20. When we take a half flaccid bladder, and expose it to any of the common sources of heat, as by holding it before the fire, or pouring hot water upon it, we invariably communicate a repulsive force to the air which it contains, causing the particles to recede from each other, and distending the bladder to a degree which, if properly confined, will cause it to burst, with a loud report. Here again we may *feel* the force which causes the aërial molecules to repel each other. Common experience has also taught us that the application of heat will quietly subdue the cohesion which binds together the atoms of the most solid metal, and which the most intense mechanical force can only very partially effect; and hence, again, we judge of the energy of the active cause.

Such are the forces of *homogeneous attraction and repulsion*;—antagonist powers which act upon the constituent particles of the same kinds of matter,—matter that is, of the same sensible properties.

§ 21. Referring back to our first acquaintance with matter, we have not only been assured of its existence, of its substantiality, of its impenetrability, of its solidity, of its fluidity by our touch, but our other senses have discovered to us different kinds of matter—matter of different sensible properties. Our taste has informed us of sapid and insipid, of acid and sweet, and bitter and saline matter; our organs of smell, of odorous and inodorous bodies; our sight, of blue and green, and black and white, transparent and opaque. It is in the reciprocal action of bodies of such different essences that we trace the existence of our next active force. If we simply dip a piece of metal, or glass, into water, and withdraw it, we shall have an illustration of it in the wetting of the solid; a portion of the liquid will adhere to it: we can estimate the amount of the force by the weight of the water which may be raised under its influence. If we repeat the experiments before referred to, of placing a few drops of water upon a fine dust, substituting powdered flint glass for resin, we shall be able to contrast this force of *heterogeneous adhesion* with that of *homogeneous cohesion*; in the former case the drops of water assumed a spherical form, under the influence of the last power; in the latter case *heterogeneous adhesion* will overcome *homogeneous cohesion*; the powdered glass will be wetted, and the water will be absorbed.

§ 22. The last force which it will be necessary to specify, to complete this general view of the forces, is CHEMICAL AFFINITY, the highest degree of heterogeneous attraction. The action of this marvellous power between the ultimate particles of different kinds of matter, constitutes matter of distinct qualities,—matter differing in essence from any of its ingredients,—matter possessing no sensible property in common with its constituent elements but that of their gravity combined. An inquiry into the laws and results of its action constitutes the chemist's peculiar province. It has been named *affinity*, from a supposed relationship of substances to each other, which fits them for intimate combination.

If we take some fragments of copper, and pour some aqua fortis (nitric acid) upon them, intense action will ensue between the liquid and the solid; abundance of aëriform matter will be evolved; the acid and the metal will both disappear, and in their stead we shall find a saline substance of a beautiful deep blue colour; the weight of which, together with that of the collected air, would be exactly that of the acid and metal thus acting upon each other by the force of *chemical affinity.* The blue matter resembles in no single property the substances from which it is produced; but that copper enters into its composition may easily be proved by dipping a piece of clean iron into its solution, when the metal will appear upon its surface, with all its characteristic properties.

The intimate and mutual penetration of bodies, under this mysterious force, might be expected to elude that kind of comparison and measure with our innate energy which we have established in the case of the other forces which have passed under our review: indeed it is not easy to conceive how a molecular action of such a kind could be immediately tested by our muscular force; but *mediately* this may be done by a reference to the force of cohesion, which is directly opposed to it. This extraordinary agent, moreover, presents itself to us in another form, in which having elicited it from the distant reaction of two masses of cold metal, by means which it will be our business hereafter to investigate, we can apply it to effect the essential changes upon matter which are the distinctive results of its operation, and at the same moment feel its powerful influence upon our muscular frame, contracting its fibres with a violence which no spontaneous exertion of our self-generated force can control.

§ 23. These illustrations may serve the useful purpose of fixing upon the minds of beginners in science some definite notions of the nature of the forces which principally concur to the production of chemical phenomena; the particular laws of their several actions, as far as they are conducive to this result, it is the object of the following pages to examine and illustrate; and for this purpose we will take them nearly in the order in which they have already been notified; and first, with regard to

GRAVITY.

§ 24. The *attraction of gravitation* is exerted between masses of matter at a distance from each other; it is that sublime power which the astronomer contemplates as extending between all the bodies of the solar system; binding the planets in their orbits, and reaching through space to countless other systems, at distances of which the mind of man strives in vain to form an adequate conception. With this stupendous and all-pervading force the chemist has little concern, except as acting at the surface of the earth, and conferring the property which we call *weight*.

It may be exemplified not only by the fall of a body to the earth, but by the approach towards each other of masses of matter which are free to obey the mutual impulse. Thus, pieces of wood, upon the surface of water, are attracted towards each other, or the sides of the containing vessel; and the wrecks of ships are frequently found aggregated together upon the surface of the ocean.

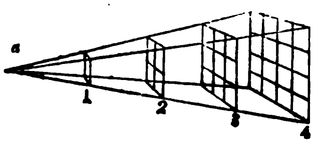
A *plummet*, or weight suspended to a string, is commonly employed to indicate a line directed immediately to the centre of the earth, and which is called a perpendicular. This is the direction of gravitation, which acts in straight lines, when undisturbed, at the surface of the globe. The same plummet, when suspended by the side of the abrupt precipice of a mountain, has been experimentally found to deviate from this perpendicular, having been drawn aside a minute, but measurable, quantity by the gravity of the mass in whose vicinity it had been placed.

In common language, we say that a stone, or other heavy body, falls to the earth: but the influence is reciprocal; the earth is attracted by the stone as the stone is by the earth. The action is directly proportionate to the quantity of matter which each mass contains, and this is the first law of gravity. The quantity of matter in the stone bearing no assignable proportion to the mass of the earth, its influence, though certain, is inappreciable.

§ 25. Here again it may be necessary to guard against a prejudice derived from careless observation, and inaccurate language: lead is proverbially said to be heavy, and a feather to be light, and when a mass of lead and a feather are suffered to fall together to the ground from a height (when abandoned, that is, at the same moment, to the action of gravity), the former reaches the bottom sooner than the latter; gravity appearing to act with greater energy upon one than the other. But if the experiment be made in a space void of other matter, the action upon both will be found to be equal; they will both fall together, and we shall learn that the retardation of the feather, in the first instance, was owing to the large surface which it presented to the resistance of the air. *In vacuo* the smallest particle of matter, and the largest mass, fall through equal spaces in equal times. *Gravity*, in short, is the power of transmitting to every particle of matter a certain velocity absolutely independent of the number of material particles: *weight* is measured by the effort which must be used to prevent a given mass, or accumulation of particles, from obeying the law of gravity; weight, therefore, depends upon the mass: gravity has no dependence at all upon it.

§ 26. The intensity of the force of gravity is measured by the velocity of a body moving unresisted under its influence, and is such, that in this latitude a body falls, in the first second of time, 16.095 feet, or about 16 feet and one inch.

§ 27. The second law of gravity is, that bodies attract one another in inverse proportion to the squares of the distances of their centres, to which their action may be referred. Now this is the law which regulates the action of all central forces,—of all forces, that is, which emanate from a centre, and spread themselves around that centre; and its generality renders it particularly desirable that we should form an accurate notion of its reason. We can best explain it perhaps by reference to light. Common experience informs us that the intensity of light decreases with its distance; and in what proportion, a little consideration will enable us to determine. A lighted taper radiates its light in all directions alike; if we imagine such a taper placed in the centre of an opaque globe, four feet in diameter, its light will all be dispersed over, and arrested by, the surface of that globe, which will be illuminated with a certain degree of intensity. If we now imagine it removed to the centre of another sphere, six feet in diameter, the same light will be spread over the larger surface, which will of course be illuminated in a less degree. The distance of the light from the surface of the first sphere would be its radius, or two feet; from the surface of the second, three feet; but the diminutions of the light would not be directly as 2 to 3, or as the mere distance, but as the squares of 2 and 3, or 4 to 9; for it can be geometrically demonstrated that the surfaces of spheres, or any similar sections of spheres, are as the squares of their radii (1);



(1) The principle may be illustrated by experiment, in the following way:—If in the annexed diagram, 1, represent a board of a foot square, placed at a certain distance from a light at *a*, it will just shadow a board of two feet square, 2,

and it is clear that in each case the light is spread over the whole surfaces, and consequently diluted in proportion to their surfaces. In the same manner, and after the same law, the action of gravity is diluted, if the expression be allowable, upon distant masses.

§ 28. If a gravitating body be freely suspended by a string, or rod, from a fixed point, it will hang in a vertical position; but if it be moved from that position by a force laterally directed, it will rise in the arc of a circle, of which the point of suspension will be the centre, under the joint action of the moving force and the tension, or cohesion, of the rod or string. When it has reached the point at which its moving force is destroyed by the counteracting forces of gravitation and cohesion, it will immediately begin to descend under the force of gravitation in the same arc; and when it reaches the vertical position, it will have acquired a *momentum* which would tend to carry it forwards in a horizontal direction; the tension of the string will, however, cause it still to move in the circle, of which the point of suspension is the centre, and it will, after passing the vertical line, rise through a similar arc on the opposite side, until its velocity is destroyed, which if no other forces than gravity, and its antagonist, cohesion, were to act, would be, when it reached a height equal to that from whence it first fell: from this it will again descend, and passing the vertical, rise to the first height; and it would thus continue to oscillate for ever but for counteracting forces. The oscillations of an invariable *pendulum*, as such an apparatus is called, are sensibly performed in equal times, or are *isochronous*, even when the arc gradually diminishes from retarding forces.

The length of a pendulum vibrating seconds, in the latitude of London (51° 31′ 08″ N.), *in vacuo*, at the level of the sea, has been accurately determined to be 39.139 in.

The force of gravity, which, on account of the figure of the earth, varies slightly in intensity from the poles to the equator, may be determined for different places by the velocity of a standard pendulum, it being directly proportional to the squares of the number of vibrations in equal times: or as the lengths of pendulums are inversely

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at double the distance; of a board of three feet square, 3, at three times the distance; or one of four feet square, 4, at four times the distance: that is to say, the light which is concentrated upon the first board would be diffused over four times the space, if suffered to fall upon the second; or over nine times the space upon the third; or sixteen times upon the fourth. The boards may be considered (without any appreciable error) as similar segments of spheres, of the radii of their several distances.

proportionate to the square of the number of their vibrations in equal times, the force of gravity may be determined for any place, by measuring the length of the pendulum, which beats seconds at that place.

§ 29. *Momentum* may be accumulated to an enormous degree in very large masses thus suspended, by forces which at their first application appear to be totally inadequate to move them. By making repeated impulses coincide in time and direction with the first minute *oscillations*, the arc will gradually increase until a great degree of velocity is produced; and the force which is thus stored up is capable of producing a corresponding concentrated effect.

§ 30. According to the first law of gravity, the force with which the earth acts upon any body at its surface, is in direct proportion to the quantity of matter which it contains; hence the measure of the force becomes the criterion of quantity: and the weight of a body is the exact amount of force, expressed with relation to some known standard, which is just sufficient to prevent that body falling to the ground. The commonest mode of ascertaining this is to oppose the known effect of the gravity of certain pieces of metal which have been compared with some conventional standard with the greatest possible exactness, to the unknown gravity of the substance whose weight or quantity of matter has to be determined. A pound is a mass of matter which has been thus adjusted; and the common business of life has rendered most men familiar with the multiples and sub-multiples of this weight, and the denominations of tons, hundred-weights, ounces, grains, &c., which have been conferred on them. The standard measure of this country is the imperial gallon of 277.274 cubic inches, and the weight of pure water which it contains is 10 lbs. The method of comparison, by means of the balance, is also well known.

§ 31. The balance consists essentially of an uniform inflexible lever, delicately supported, at its centre of gravity, on a fine knife-edge, and carrying scale-pans freely suspended from points in the same horizontal line with the centre of gravity. If the weights, or quantities of matter, in each be equal, the one will counterbalance the other, and the beam will remain horizontal; if not, the heavier will preponderate. Lightness of construction, and freedom of motion, are secured by many ingenious contrivances, upon which it would be foreign to our present purpose to dwell. A good balance will indicate by its turn $\frac{1}{5000}$th or $\frac{1}{6000}$th of the weight which it is designed to carry, and will freely move with the difference of $\frac{1}{1000}$th of a grain.

§. 32. Equality in the length of the arms of the lever is, of course, the most important consideration in the construction of the balance; but when there may be any reason to doubt this essential point, it is well to know that any error may be avoided by the method of *double weighing*. This consists in placing the object whose weight is to be ascertained in one scale-pan, and exactly counterbalancing it in the other, not with the weights, but with sand or shot, or any other indifferent substance. The substance is then removed, and the weights applied in the same pan, till the counterpoise is balanced. By this contrivance the unknown quantity of matter is compared with the known, under exactly equal circumstances, and the result is independent of almost every source of error which can affect the comparison of one object with another.

§ 33. The second law of gravity has little to do with the determination of weight, and for this purpose may safely be disregarded; for any variation of the distance from the centre of the earth, at which we may carry on our operations, is so small, with regard to the whole, as to be perfectly insignificant, although not inappreciable to the refinements of modern science. The mean radius of the earth, or the distance from the centre to the surface, is about 3,941 miles; and supposing that we had to determine the weight of an object on the summit of a mountain one mile in height, the force of gravity would be decreased in the ratio $3942^2 : 3941^2$, which would make a difference of about one ounce in a ton weight. This difference would not of course be apparent in the usual manner of weighing, by means of the balance; for the decrease of gravity would affect both the weight and the object to be weighed in the same degree; but it might be measured by the opposition of another force, as that of elasticity. A spring which would be bent to a certain degree by a ton weight, at the surface of the earth, would require a ton weight and one ounce to bend it to the same amount on the summit of the mountain.

§ 34. Every substance in nature, occupying a given space, is found to have, under the same circumstances, a weight *specific* or peculiar to itself; or, in other words, the same volume of different kinds of matter contains different quantities of matter. The comparative weights of equal bulks of different bodies are called *specific gravities*. This is a very important distinctive property of matter, and one to which the chemist has perpetual occasion to refer. In comparing specific gravities it has been found convenient to refer them to a fixed standard, and water has been generally adopted for this purpose, as being easily procurable in most times and places.

§ 35. The mode of taking the specific gravity of a liquid is very simple and easy of execution. A small stoppered flask is prepared to contain exactly 1,000 grains of pure water; this is filled with the liquid, and placed upon the balance; in the opposite pan is placed the counterpoise of the bottle when filled with water, and when heavier than water so much weight as will adjust the beam. If the liquid be lighter than water the weight must be placed in the same pan with the bottle.

In the first case the weight in grains added to 1,000, and in the second case deducted from 1,000, will give the specific gravity sought. Thus the same bottle which held 1,000 grains of water, was found to contain only 839 grains of spirits of wine; and, taking water as 1, the specific gravity of the spirit is said to be 0.839.

§ 36. It would be impossible thus directly to compare a given volume of any solid body with an equal volume of water; were there no other obstacle, it would require a nicety of measuration and workmanship which would be quite unattainable. But the same end may be obtained with perfect accuracy by means which are easily applied. The rule is to weigh the solid in air and afterwards in water, and having found the deficiency of the latter weight, to divide by it the former, and the quotient will be the required specific gravity. Now there is nothing more injurious to the progress of a student in any science than the acquirement of such rules by rote, without a thorough comprehension of the principles upon which they are founded; they may thus be rendered available for mere practical purposes, but they are utterly useless as steps in his advancement. For instance, how many thousand persons are there who can (to make use of a common expression) work the rule of three, without in the least understanding the doctrine of proportion upon which it is founded? With less trouble than it takes them to learn and recover the rule, which they are in constant danger of forgetting, they might attain to a knowledge of its principles, which would not only be of general application, but a help to further improvement. A little consideration will be sufficient to render the principles of the above process perfectly clear. When a solid is wholly immersed in water, it obviously displaces a bulk of that liquid exactly equal to its own, which bulk was supported in its place by a pressure from the surrounding particles equivalent to its own gravity: this may be easily proved by the familiar illustration of a bucket in a well. When the full bucket is wholly immersed in the water, it requires scarcely any effort to draw it to the surface; but the moment it rises above the water the weight of the water is felt, being no longer supported by the surrounding liquid. In the process, therefore, of taking specific gravities, the solid immersed must also be supported by the surrounding water with a force exactly equal to the weight of the water which it has displaced, and thus the difference of its weight in water from that of its weight in air must be the weight of an equal bulk of water. The direct comparison of the substance with water having been thus effected, a number bearing the same ratio to unity is easily found by the rule of proportion, and this will be the specific gravity. An example may, perhaps, render this more clear. A lump of glass is found to weigh in air 577 grains; it is delicately suspended by a horse-hair from the bottom of the scale-pan, and immersed in a vessel of pure water, it is found to weigh 399.4 grains; the loss, therefore, or the weight of an equal bulk of water, is 177.6 grains; then 177.6 : 1 : : 577 : 3.2; the working of which sum resolves itself into the division of the third term by the first, or of the weight in air by the weight in water, according to the rule. The quotient 3.2 being the specific gravity of the glass.

Solid bodies, lighter than water, such as cork, may be weighed by attaching to them a mass of metal, or glass, previously balanced in water for that purpose, which may cause them to sink, and then proceeding with the combined mass as before.

§ 37. The same principles may be applied to ascertain the specific gravity of liquids, instead of the specific-gravity bottle; for as a bulb of glass immersed in water is buoyed up by a force equivalent to the weight of an equal bulk of water; so when immersed in any other liquid, it will be supported by a pressure equal to the weight of a similar bulk of that liquid. Thus the mass of glass which lost 177.6 grains by immersion in water, was found to lose only 149 grains by being plunged into the spirits of wine, and their two amounts are consequently the weights of equal bulks of water and spirit; therefore 177.6 : 1 : : 149 : 0.839, the specific gravity of the spirit.

§ 38. It is upon the same principle that the specific gravities of liquids, which do not differ much from one another, may be determined by the *hydrometer*. This instrument consists of a hollow ball of glass, or metal, with a weight below it, and a slender stem above, divided into a certain number of degrees by marks; in pure water it is adjusted to float to a particular mark; that part of the stem which is out of the liquid acts as a weight to keep it in its place. When immersed in a lighter liquid, such as spirit, the lateral pressure which supports it is diminished, and not being sufficient to support the same weight as before, the instrument sinks, till a portion of the stem becoming immersed, its weight is decreased, and the balance again restored. Sometimes the instrument is adjusted to different liquids by moveable weights, while the graduations of the scale are made to express the specific gravities by the degree to which it sinks (2).

§ 39. From what has been said, it will upon reflection be clear, that when in ordinary circumstances a bulky body is counterpoised by a weight of very dense matter, an allowance ought to be made for the unequal buoyancy of the air; and this may be rendered evident by balancing a piece of cork with a counterpoise of metal, and afterwards placing them in a space devoid of air, when the former will preponderate. If the volume of the cork were 2.5 cubic inches, it would require nearly half a grain to restore the balance, this being about the difference of the weights of the air which the two bodies displaced. For ordinary purposes the effect is too small to require to be taken into consideration, but in nice scientific investigations it is often estimated.

But the force with which a body is attracted to the earth, and, consequently, the quantity of matter which it contains, may be measured by opposing to it other forces than that of gravity. We can even roughly judge of different weights by the different degrees of muscular exertion necessary to support them; and we have already had occasion to refer to a method of estimating them by the compression of a spring. This observation will naturally lead us to the consideration of our next force; namely,

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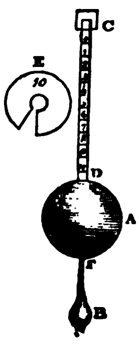

(2) The annexed figure represents Sikes's hydrometer. A, is a brass ball, into which a conical stem, F, is inserted, terminating in a loaded ball, B; at D a flat stem is inserted, which is graduated into eleven equal parts, each of which is subdivided into two; eight circular weights, E, are adjusted to the instrument, in which a slit is cut, so as to admit the slender part of the lower stem into the hole in the centre of the weight; their use is to adapt the instrument to liquids heavier than water. A set of tables are furnished with the instrument, by which the specific gravity of a spirit is easily ascertained after an observation of the degree upon the stem to which it sinks.

ELASTICITY.

§ 40. The immediate resistance of a body to compression, or extension, is properly called its elasticity. It has been exemplified by the sensible effort of a compressed spring, and a bent bow, to recover from their forced state of flexure. It is directly proportionate in perfectly elastic bodies to the compressing force; and this is the law of its action. If a bow be drawn to a certain extent by a seven-pounds weight, it will be drawn to double that extent by fourteen pounds; and upon this principle various spring-balances have been contrived.

The kind of elasticity to which we have hitherto referred arises from a force longitudinally applied, and a partial displacement of the particles of a solid in length, and is denominated *flexure:* a second kind consists in the lateral displacement of the opposite parts of a solid, in opposite directions, the central parts only remaining in their natural state, and is called *torsion* or *twisting*. Elasticity thus elicited may be very accurately measured by the angular displacement; the angle of torsion being exactly proportionate to the degree of elasticity. Balances of the greatest delicacy have been constructed upon this principle, for the estimation of minute degrees of force.

But solid bodies are only more or less elastic within certain limits; the operation of forces beyond these limits first produces a permanent alteration or change of figure, which is called *setting*, and afterwards *fracture*. The most perfect examples of elasticity are afforded by aëriform bodies, and the atmosphere which surrounds us furnishes a beautiful illustration of the equilibrium of this force and gravity, a correct understanding of which is of the greatest importance.

§ 41. With regard to matter in the aëriform state, common experience is by no means sufficient, as with solids and liquids, to teach us how to collect, confine, or weigh it; and it was not till the time of Galileo (or early in the seventeenth century,) proved that the air had a definite weight and pressure; and it was some time after this that Dr. Priestley contrived the simple means which are still in use for experimenting with such fluids. Aristotle indeed appears to have happily guessed the truth; and Plutarch informs us that he assigned the gravity of air to be between that of fire and earth; but the surmise appears to have led to no particular consequences, and to have been forgotten.

§ 42. If we take a bell-glass, and press it with its mouth downwards into a deep vessel of water, we find a strong resistance to its descent, which arises from the body of air confined beneath it; as we press upon it more and more, we feel a stronger and stronger opposition or repulsive force; the water rises further into the interior, and the air occupies a less space; as we withdraw the pressure, it returns to its former bulk, and totally displaces the water. Hence we may learn that the air is elastic, like the spring to which we have just referred; and we can roughly estimate by our feeling that its elasticity increases in proportion to the force with which it is compressed. We learn likewise from the same simple experiment that the volume decreases with the increase of pressure. The law of its elasticity was originally developed by Boyle, but Mariotte more accurately determined by experiment that the volume of air was always inversely as the pressure (3). Elastic fluids of this nature always occupy the whole of any vessel in which they may be contained, whatever their quantity of matter may be, as determined by their weight; liquids or fluids devoid of this power of elasticity, in vessels which they do not fill, always present a level surface,—*i. e.*, a surface parallel to the general surface of the globe. This is determined by gravity, the law of which they are free to obey, unopposed by any counteracting force; the surface of an elastic fluid is always coincident with that of the containing vessel in which it is confined.

§ 43. If we take a strong tube or barrel of metal or glass, closed at one end, and closely fitted at the other with a piston, or moveable plug of leather, which will not allow of the passage of

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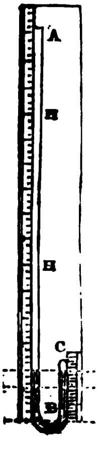

(3) This figure represents the form of Mariotte's experiment. A B is a glass tube, turned up, and closed at the end, C; it is divided and graduated into equal parts; mercury is poured into it, so as to occupy the lower part of the tube to the first horizontal line, and a portion of air is inclosed at C, of the ordinary elasticity, which it will be hereafter seen is equal to the pressure of about thirty inches of mercury. If more mercury be now poured into the longer leg, so that it may stand at thirty inches above the level of the mercury in the shorter leg, it will press with its whole weight upon the included air, which will then be found to occupy only half its former space. If, in like manner, the column of mercury be increased to twice this length, the pressure upon the included air will be tripled, and the space occupied by it will be reduced to one-third, &c.

air at its sides, on pressing it downwards we shall find the same kind of increasing resistance from the included air, as in the case of the bell-glass under water. This elastic force may be made to perform mechanical work; and if the piston be perforated, and the perforation be covered with a valve, or little door, opening upwards, as we press it down the elasticity of the air will raise the valve and allow it to escape, and the piston will freely descend. If we attempt again to draw the piston up, we shall feel a strong opposition in the contrary direction. As the piston rises, an empty space is left between it and the bottom of the barrel; for the exterior air, in attempting to pass in, by its elastic force firmly closes the valve. If by strong muscular force we succeed in drawing the piston up, upon discontinuing the effort it will be forced down again to the bottom by the exterior pressure. Let us suppose now the bottom of the barrel to be fitted with the same kind of valve as the piston; as the latter ascends, the elasticity of the portion of air included in any vessel with which it may be connected will raise the valve, and the air will flow into the barrel: when the piston is again forced down, this valve will be closed by the force above it, and the included air will again pass off through the piston-valve, and we can repeat this operation, gradually withdrawing barrel-full after barrel-full of air from any vessel till the residual air becomes so reduced as not to have elastic force enough to raise the valve. Two such barrels so fitted with pistons, with a mechanical apparatus, for alternately raising and depressing them, constitute the essential parts of the air-pump (4).

§ 44. Now if we take a thin glass globe or flask, fitted with a stop-cock, we may by these means exhaust it of the greatest part of the air which it contains, and equipoise it upon the balance. Upon opening the stop-cock, air will rush into the empty vessel, and it will preponderate; and it will require a considerable weight in the opposite scale to restore the equilibrium. To ascertain the exact weight of any given volume of air, it will be necessary to measure it, and this we cannot do by measuring the capacity of the globe, for the best air-pump will always have a residual quantity after exhaustion; but by connecting the exhausted vessel with an accurately graduated jar (5), standing upon the water-bath, the air may be made to enter from the latter, and the rise of the water into the jar will indicate the exact quantity which has been thus

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(4) *a* and *b* in the adjoining figure represent the cylinders, in which the pistons, *c* and *d*, are accurately fitted; at the bottoms of the cylinder are the valves *h*, *h*, opening upwards; and in each piston is a valve *g*, *g*, also opening upwards; the bottoms of the cylinder are connected by a tube, *e*, with the pump-plate, upon which stands the bell-glass, *f*; in the cylinder *a*, the piston is represented in the act of ascending, when the valve *g*, is closed, and a vacuum would be formed beneath the piston, but for the opening of the valve *h*, by the elasticity of the air in the receiver. In the cylinder *b*, the piston is in the act of descending when the valve *h* is closed, and the valve *g* open, by which all the air in the cylinder is

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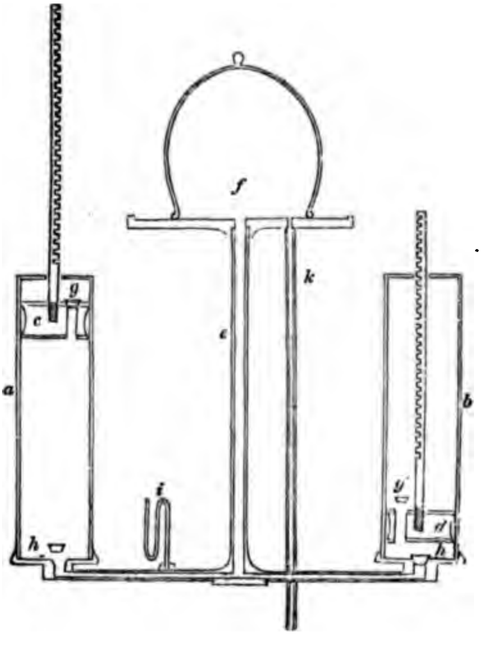
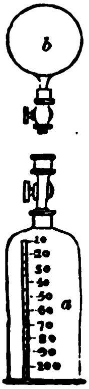
forced out; and in this manner a portion of the air is withdrawn from the receiver *f*, at every stroke of the pump.





(5) *a* represents the air-jar, graduated into cubic inches, and parts of a cubic inch; *b*, the glass balloon; each is fitted with a stop-cock, and connecting-piece.

abstracted (6). By careful experiments, conducted upon this principle, it has been found that 100 cubic inches of atmospheric air, under standard circumstances, to which we must hereafter advert more particularly, weigh 31 grains,—or 815 times less than an equal bulk of water. We shall find that there are many different kinds of aëriform matter, differing very greatly in their specific gravities: this is the mode by which they may be ascertained, and atmospheric air is the standard to which they are all referred, just as the specific gravities of solids and liquids are compared with water.

In the following table are included the weight of 100 cubic inches of the lightest and heaviest known forms of matter: of the same quantity of atmospheric air: and of water in its three physical states. The specific gravity of each, compared with air and water, is also shown.

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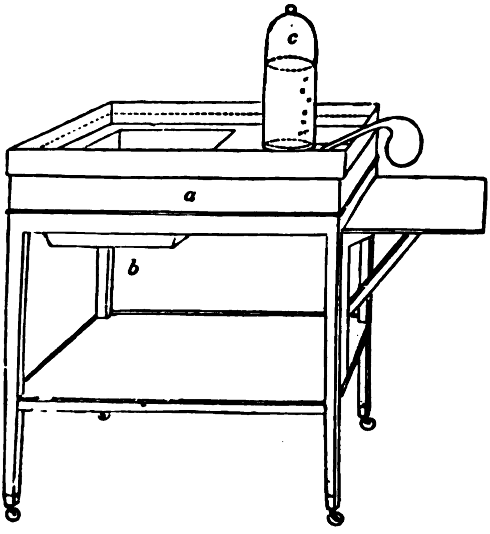
(6) The most convenient table for collecting or transferring gases is here represented: *a* is the wooden stand which holds the water-bath, which consists of a deep well at *b*, in which the jars may be filled with water,



and a shallow shelf, upon which, when inverted, they may be placed; at *c* a jar is represented standing over a groove, by which the gas, disengaged from the retort, is conducted into it. The gas gradually rises in bubbles, by its levity, and displaces the water.

TABLE I. *Of Specific Gravities.*

	Cubic Inches.	Weights. Grains.	Specific Gravity, Air 1.	Specific Gravity, Water 1.
Hydrogen .	100	2.138	0.0694	0.0000846
Air . .	100	31.000	1.0000	0.0012277
Steam .	100	19.220	0.6240	0.0007611
Ice . .	100	23735.000	765.0000	0.9400000
Water . .	100	25250.000	814.0000	1.0000000
Platinum .	100	542875.000	17512.0000	21.5000000

§ 45. The weight or pressure of the atmosphere was first, however, demonstrated in a different way by a celebrated Italian philosopher, named Torricelli, in the year 1643. His attention was drawn to the subject by the attempt of a well-digger, at Florence, to raise water by a sucking-pump to a height exceeding 33 feet. The rise of water in a tube, by these means, had up to that time been ascribed by philosophers (who, as it is to be feared sometimes now happens, disguised their ignorance under the cloak of indefinite and specious expressions) to *Nature's abhorrence of a vacuum*. The well-digger failed in his enterprise, and applied to Torricelli for advice; who, seeing the absurdity of the conclusion that nature only abhorred a vacuum to the extent of 33 feet, suspected that the cause of the ascent of water in the pump-pipe might be the pressure of the atmosphere; and that a column of water of about the height mentioned, was sufficient to equipoise the air (7). He concluded that if this were the case it would only support a shorter column of any denser fluid, and he immediately had recourse to experiment to

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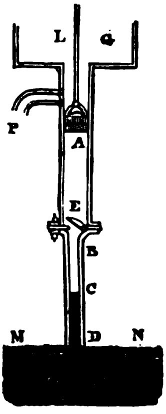

(7) The annexed figure represents the construction of the common sucking-pump: A, B, is the barrel fitted with a piston, in which is a valve at A, opening upwards; another valve E, at the bottom of the barrel, also opening upwards, closes the communication with the pipe, B, D, which descends below the level of the water, M, N. As the piston rises, a partial vacuum is formed beneath it, and the superior elasticity of the exterior atmosphere pressing upon the water, M, N, forces it to ascend into the pipe from D to C. The descent of the piston closes the valve E, forces out another portion of the air through the valve A, and upon its return the valve B again opens, and the water is forced past it into the barrel. Another stroke of the pump drives the water past the valve A, also, and lifts it into the reservoir L, G, from which it flows, through the aperture P.

confirm his conjecture. He filled a glass-tube, three feet long, and closed at one end, with quicksilver, and inverted it in a basin of the same fluid; it immediately sank about six inches from the top of the tube; proving that the pressure of the atmosphere which could support a column of water of about 33 feet in height, could only support a column of mercury of 30 inches, the height of the columns being in exact proportion to the specific gravities of the two liquids, or as 13½ to 1 (8).

§ 46. Thus was invented that useful instrument the *barometer;* for a tube filled with due precautions wholly to exclude the air, and accurately adjusted to a scale for the purpose of measuring the exact height of the column from the surface of the mercury in the cistern, constitutes the essential part of this simple but highly ingenious contrivance (9). In confirmation of the principles upon which it had been constructed, it was soon observed that upon ascending a hill the quicksilver fell in the tube; obviously because the column of air was shortened which supported it. This observation was, not long after, applied to the measurement of heights.

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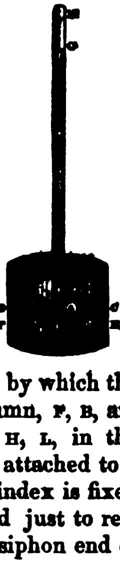
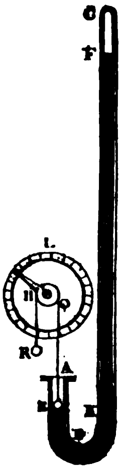
(8) H, B, represents a tube, which having been filled with mercury, and closed with the finger, has been inverted carefully beneath the surface, D, C, of the mercury in the glass basin, D, C, F, E. Upon removal of the finger from B, the mercury has fallen in the tube from H to G, the column of mercury, A, G, being the exact equipoise of the elasticity of the atmosphere at the time of the experiment.





(9) In this figure is represented the mode by which the fluctuations of the height of the mercurial column, F, B, are indicated by the index upon the dial-plate, H, L, in the common wheel-barometer; a glass weight, E, attached to a thread, passing round a pulley, to which the index is fixed at B, and nearly counterpoised at R, is allowed just to rest upon the surface of the mercury in the open siphon end of the tube at A; it consequently rises and falls as the column, B, E, becomes longer and shorter, and the motion of the thread turns the pulley, and moves the index through the arc of a graduated circle.

The gravity and elasticity of the atmosphere react upon one another in such a way that the space which the same absolute weight of air occupies at different heights, must be the measure of both. If we suppose it divided into strata of equal thickness from the top, the first stratum will press downwards by the whole of its own weight, but by nothing more; the second will press downwards by its own weight, and will be compressed by the weight of the first in addition; a third will have to support its own weight and the weight of the two preceding; a fourth will be compressed by three, and so on, each stratum being compressed by the whole thickness of the one above it. Thus the pressures at different heights will be inversely as the squares of the distances from the surface of the earth, and will be measured by corresponding diminished heights of the column of mercury in the barometer. Thus, supposing the length of the equiponderant column, at any given time, to be 30 inches at the level of the sea, at the height of

5,000	feet it would be	24.797	inches.
10,000	„ „	20.499	„
15,000	„ „	16.941	„
20,000	„ „	14.000	„

§ 47. The mean height of the barometer at the level of the sea is very nearly 30 inches, but a very little observation will prove that it is subject to perpetual oscillations within the limits, in this country, of about two inches and a half; these are dependent upon agencies which we will endeavour to develope at a more advanced period of our inquiry. We may at once, however, remark, that the existing pressure of the atmosphere regulates the elasticity of every portion of aëriform matter inclosed in jars or bell-glasses inverted over water, or any other liquid. If such a glass be carefully turned down upon the water-bath, so that the water may stand at the same level both inside and out; it is clear that it will enclose a portion of the atmosphere of the existing elasticity: supposing the glass to have been filled with water, and afterwards with any elastic fluid thrown up into it, by that kind of upward decantation by which air, from its comparative levity, may be made to displace the heavier fluid, its elasticity must be governed by the same exterior pressure. It is necessary, therefore, to take the amount of this variable pressure into consideration, in taking the weight of any air by the process previously described (§ 44), and to assume some fixed pressure to which they may all be referred in taking their specific gravities. This standard pressure is 30 inches of mercury, and nothing can be more simple than the calculation by which observations made under any other pressure may be reduced to this standard: the law being kept in mind, that the weight is always directly, and the volume inversely, proportionate to the pressure. Suppose, for instance, that, with the barometer at 29 inches, we had found the weight of 100 cubic inches of air to be 29.9 grains, and wished to know what the weight would be at standard pressure—by the rule of proportion we shall find, 29 : 30 : : 29.9 : 31.0. Or, suppose that we had measured 100 cubic inches of air, at 29 inches, and wanted to know what the volume would be at 30 inches, we shall have 30 : 29 : : 100 : 96.6.

§ 48. In measuring gases over the water, or mercurial baths (10),

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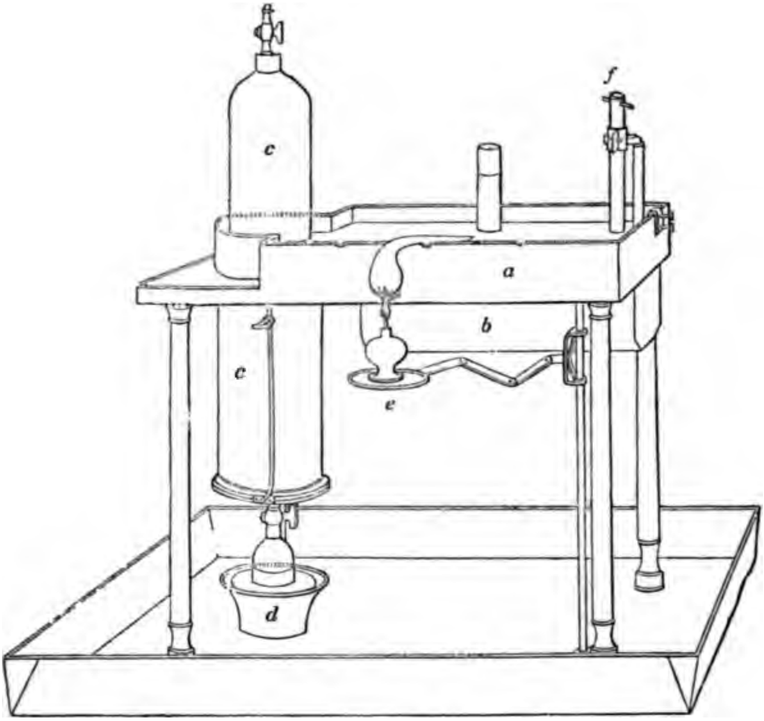
(10) The mercurial bath is here represented, by which gases which are liable to be absorbed by water may be collected and transferred; it is constructed of iron: *a* is the shallow part of the bath, and *b* the well for filling the jars; *c* is a glass jar, serving the purpose of a reservoir. It may be filled with any gas, by first pressing it down into the cylinder *c*, in which is an iron core, the interval between which and the exterior case is filled with mercury, and then allowing the gas to rise into the small bell-glass placed in the basin of mercury, at *d*. A jar, partially filled with gas, is represented at *a*.



it is also necessary to take care that the liquid within and without the vessel stand at the same level; and where this cannot be effected by plunging it into the deeper part of the bath, the difference of level must be measured, and the following simple correction applied. Suppose a quantity of air confined over mercury, the level of which stands higher by two inches within the jar than without, it must be obvious that the pressure of the atmosphere balances not only the elasticity of the included air, but the weight of the mercury within the jar; the elasticity of the air must therefore be less than that of the atmosphere at the time, by an amount of which the difference of the level is the measure; under the circumstances, two inches must be deducted from the height of the barometer, and the correction for pressure applied as before. Should the difference of level occur with water, it may be reduced to the corresponding difference of mercury, by dividing it by 13.5, the difference of the specific gravities of the two liquids (11).

§ 49. The atmosphere presses upon the surface of the earth, and upon the surfaces of all bodies which are plunged into it, with the same force as that by which it supports the mercury in the barometer; and a column of mercury, 30 inches in height, whose base is one square inch, would weigh about 15 lbs.; and would press upon the earth with the same force; every body, therefore, upon the surface of the earth, at the level of the sea, supports an average pressure of 15 lbs. upon every square inch of its surface. That we are not sensible of this pressure on our own persons, and on all surrounding objects, is owing to its equality in all directions. From the fluidity of the atmosphere,—the perfect mobility of its particles,—any force is equally distributed throughout its mass, and its gravity not only presses downwards, but upwards, and laterally, and in every direction alike. If we destroy this equilibrium, as we may easily do by the air-pump, the pressure becomes immediately manifest; almost the first stroke of the pump fixes the receiver to the plate, and after the air has been exhausted to the utmost we may raise the weight of the pump itself without detaching it. It is for the purpose of enabling them to bear this enormous pressure that such glasses are made of a spherical form. If a glass of a cubic shape be exhausted, it is speedily crushed to atoms; or, if a bottle of a similar shape be hermetically sealed, when filled with air of the usual density, and enclosed under a receiver from which the air is pumped, the elasticity of the included air no longer being counteracted by the exterior air it will burst outwards with equal violence.

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(11) The rarefaction of the air in any vessel connected with the air-pump, may be measured by gauges, acting upon the principle of the barometer. In figure 4, (page 28) *k* represents a barometer-tube, opening under the receiver, *f*, and dipping at its lower end into an open cistern of mercury. As the air under the receiver becomes rarefied, the superior elasticity of the atmosphere raises up a column of mercury, which, upon the supposition of the total abstraction of air, would stand at the same height as the barometer. The difference between the two, measured upon a scale of inches, indicates the elasticity of the residual air. The siphon-gauge, at *i*, does not begin to act till the rarefaction has been carried on to a very great extent. The upper part of the siphon is filled with mercury by boiling, which is kept in its place by the pressure of the air; when this is diminished to such a degree as not to be able to support a column of mercury equal in height to the upright part of the tube, it begins to fall away from the top, and to rise in the parallel leg of the siphon, and, as the equality of these two columns would denote a perfect vacuum above each, the elasticity of the air in the receiver, with which the instrument is connected, is measured by their difference

It is curious to remark how frequently common experience has anticipated science in the application, if not in the formal announcement, of scientific principles. A beautiful illustration of the expansive power of heat, and the pressure of the atmosphere, occurs in baking a fruit pie. The cook inverts a cup in the dish, from which a portion of the air is expelled by the heat of the oven; when allowed to cool, the remainder contracts, and a partial vacuum being formed, the pressure of the atmosphere forces the juice to rise in the cup, and thus prevents its coming in contact with the crust, by which it would be absorbed.

§ 50. The surface of a man of ordinary stature is about 15 square feet, so that the atmospheric pressure upon his body amounts to 14 tons; this he sustains with perfect convenience, because every cavity of his body is distended with aëriform matter of the same elastic force. He also moves about under this enormous load without being conscious of its existence, owing to the equality of its action: could we suppose the air to cease to press in an upward direction, while its downward weight continued, he would be bound to the spot on which his foot rested as effectually as the rooted oak. Something of this we may indeed feel from the fatigue we endure in walking upon a stiff clay. In such a soil the air is more or less pressed from under the feet, and just upon the same principle that the boys' plaything, called a sucker, raises the weight of a large stone, a strong effort is necessary to overcome this unequal pressure.

Those who ascend into the higher regions of the atmosphere, by climbing lofty mountains, or by balloons, often feel inconvenience in their ears, and other cavities of their bodies, from the included air not having time to adjust itself to the diminished pressure of the outward medium; and it is no wonder that persons of weak constitutions often feel considerable discomfort from sudden changes of the weather, when barometric oscillations may indicate a change of pressure upon their bodies of 18 or 20 hundred weight in the course of a few hours.

§ 51. The alternate action and reaction of mechanical force and elasticity, and the consequent propagation of force to a distance, by *vibration*, are beautifully illustrated by the phenomena of SOUND. The complete developement of the subject constitutes a distinct branch of science, under the name of *Acoustics:* we can only here advert to the play of the forces which are concerned in its production.

When the particles of an elastic body are suddenly disturbed by an impulse at a particular point, the force spreads throughout their substance from that point, as a centre, and they return to their state of rest, by a series of *isochronous vibrations*, or rapid movements to and fro; equal numbers of which take place in equal times. The rapidity, force and permanence of these vibrations depend upon the elasticity, the form, and the mode of aggregation of the particles of the vibrating body. They are not confined to the substance in which they are produced, but they communicate themselves to the surrounding air in which, on account of its elasticity, they excite equivalent condensations and dilatations which again are propagated to a distance. The corresponding impulses produced upon the ear constitute sound. If the successive impulses form a connected series, following each other too rapidly to be separately distinguished, they constitute a continued sound like that of the voice in speaking; and if they are equal among themselves in duration they produce a musical or equable sound, as that of a vibrating string, or of the voice in singing. A quill striking against a piece of wood causes a noise, but striking against the teeth of a wheel, or of a comb, a continued sound; and if the teeth of the wheel be at equal distances, and the velocity of the motion of a certain amount, and constant, a musical note (12). The lowest sound which can be called musical, is produced by 16 vibrations in a second of time; though, according to the observation of Dr. Wollaston, some ears are so constituted as to be able to appreciate notes at both extremities of the scale, which are inaudible to others. The higher octave to this sound is produced by double the number of vibrations, and the double octave by four times the number in the same time, and so on in the progression 16, 32, 64, 128, 256; the last of which produces the note which is designated as the middle C on the pianoforte. The fixedness of these relations is such that the well-known sound of the different musical notes has been employed by Professor Wheatstone as the measure of velocities in machines which are utterly inappreciable by ordinary mechanical means.

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(12) A B represent the two prongs of a tuning-fork made of steel; if one of them, A, be struck against a solid substance it will

A certain time is always required for the transmission of an impulse through a material substance, and this time varies with its hardness and compressibility. The velocity of sound in air has been found by experiment to be 1130 feet in a second; in water, 4900 feet; and along a deal rod, 17,400 feet.

§ 52. As the force from the original impulse diverges in air, and spreads through a spherical space, its intensity must decrease as the square of the distance, but it is capable of being turned back or reflected from the surface of any solid obstacle.

§ 53. A musical string gives a very feeble sound when vibrating alone, on account of the small quantity of air set in motion; but when attached to a large surface of wood, or to what is called a sounding-board in musical instruments, it communicates its oscillations immediately to that surface, and the whole system vibrates isochronously. The extensive vibrating surface again trans-

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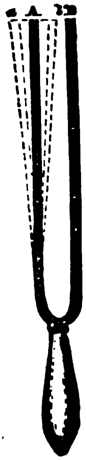
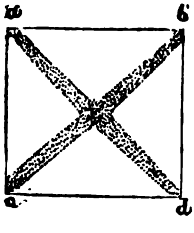


momentarily assume the position, *b*, nearer to the other prong, B, but from its elasticity it will immediately return to its former position, beyond which it will be carried by its momentum to the position *a*, about as far from A as the second position, *b*, and thus a series of rapid vibrations is brought about, which being propagated through the air to the ear produces the sensation of a musical note.

mits its motions to the surrounding mass of the air, and the sound is much increased.

§ 54. The oscillations of a solid body are not confined to one direction, but may be longitudinal, transverse, or rotatory, in every plane, or confined to one plane, accordingly as the impulse is communicated. Differences in the structure of a body may influence the direction of its vibrations. If a little fine dry sand be strewed over a vibrating surface, it will be thrown into violent agitation by the force communicated to it in particular situations, but in other situations it will remain at rest, and it will thus enable the eye to distinguish the vibrating from the quiescent parts. Thus, if vibrations be excited in a plate of glass or metal, by drawing the bow of a violin across its edge, it will emit a musical sound, and the sand will immediately arrange itself in certain lines regularly disposed, where it will accumulate from other parts, and remain at rest. It is thus found that the adjacent divisions of the surface are in different states of vibration, some being always elevated while others are depressed; and the oppositely vibrating parts are separated by lines of rest. These lines of rest are termed *nodal lines*, and they vary in form and position with the part where the bow is drawn across; but the point by which the plate is held being necessarily in a state of rest, must be included in a nodal line (13). Similar points of rest, or nodal points, are found on a vibrating string; and pieces of paper placed at the half, third, fourth, or other aliquot points of its length, will remain on it during its vibration, but will instantly fly off from any intermediate points. They are points of equilibrium between two adjacent oppositely vibrating parts. Indeed all vibrating bodies have a tendency to divide themselves into a certain number of parts which perform these vibrations independently of each other.

§ 55. The amount of force which may be accumulated from



(13) If a plate of glass, *a*, *b*, *c*, *d*, be held horizontally at its centre, E, between the finger and thumb, and sand be scattered over its upper surface, upon causing it to emit a musical note, by drawing a violin-bow along its edge, the sand will arrange itself in lines constituting regular figures, the form of which will depend upon the pitch of the note. The lines *a*, E, *b*, E, *c*, E, *d*, E, in the figure, represent a common arrangement of these nodal lines; the point, E, by which it is held, will be, of course, quiescent.

the frequent and regular repetition of minute impulses to the particles of elastic solids is very great, just as momentum may be accumulated in a pendulum by frequent small impulses (§ 29) ; and the cohesion of glass itself has been known to yield under the intense vibrations of a musical note. If we pass our moistened fingers lightly along a glass tube, two or three yards in length, and from three-fourths of an inch to an inch in diameter, we may generate a force which will be sufficient to move a leaden ball placed within it, and even to draw it up against the action of gravity, when the tube is inclined several degrees to the horizon. Or if we fix a small glass tube into a beam of wood, and cause it to vibrate longitudinally, in the same way, the successive and periodic impulses will be sufficient to agitate the beam throughout its mass, and to produce vibrations of such an extent that whole handfuls of sand thrown upon it will be projected upon the lines of rest, which will thus be accurately defined.

§ 56. These vibrations alter the molecular arrangement and strength of bodies while they last, so that if a weight of 90 pounds be suspended from a copper band of three yards in length, 0.4 inch wide, and 0.04 inch thick, it will remain unchanged for any length of time; but if made to vibrate, it will become lengthened six or seven inches. M. Savart has lately measured the lengthening of rods of glass and brass by the act of vibration, under the friction of a damp cloth, and ascertained the amount of mechanical force which would be required to be directly applied to produce the same effect, and found it to be in the first case, (the diameter of the cylinder being 1.14 inches,) equal to a weight of 2000 pounds; and in the second, (the diameter being 1.38 inches,) 3800 pounds. The facts are of the utmost practical consequence with regard to structures in metal which are destined to support great weights, and are at the same time exposed to regular oscillations and vibrations.

We will now direct our attention to the forces of

HOMOGENEOUS ATTRACTION AND REPULSION.

§ 57. THE force of COHESION in bodies is measured by the amount of any force which may be required to separate their particles, or break them, and may be ascertained by experiment. The opposing force may be applied in various ways. (1) It may tend t tear the body asunder, in the direction of its fibres; (2) it may tend to break the body across; (3) it may tend to crush the body; (4) it may tend to separate the particles by means of torsion or twisting.

The investigation of the strength of materials, and the different degrees in which they resist the action of force, so variously applied, belongs to mechanical science. The following table shows the force of cohesion from experiment of a few solids, as indicated by the weights required to tear them asunder, and to crush them.

TABLE II. *Of Strength of Materials.*

Bars 1 inch square torn asunder.			Cubes of ¼ inch crushed.
Cast steel	140,000 lbs.		—
Cast iron	—		10,000 lbs.
Cast copper	19,000 lbs.		7318 lbs.
Wrought copper	33,000 lbs.		6440 lbs.
Brass	17,000 lbs.		10,304 lbs.
Tin	4700 lbs.		966 lbs.
Lead	1800 lbs.		483 lbs.
Elm	5800 lbs.	1 in. cubes	1284 lbs.
Pine	10,400 lbs.		1606 lbs.
Oak	10,000 lbs.		3860 lbs.

§ 58. The force of cohesion is opposed to mechanical force in the case of the surfaces of two solids of the same substance moving upon each other, and is estimated by the resistance to the motion, which is denominated *friction*.

Friction is greatest between rough surfaces, and diminishes with the degree of polish given to them.

All other circumstances being equal, it is directly proportioned to the pressure of the two bodies. Friction also arises from a similar opposition of the force of adhesion, in the case of the two surfaces in motion being of dissimilar matter; but it is greater between homogeneous substances than between heterogeneous ones.

§ 59. The subject of FRICTION, again, is purely mechanical; but we re-enter within the strictest limits of our department in considering next, those adjustments of the two antagonist powers of homogeneous attraction and repulsion, which constitute the physical states of solid, liquid, and aëriform. The best, because the most familiar, illustration of these three different states, may be derived from our every day observation of the changes which water undergoes. Every one knows that by abstracting heat from water, or cooling it to a certain point, we can convert it into a solid which we call ice; we diminish the repulsive force, and the attractive gains the ascendency. The amount of this cohesion we can estimate by the mechanical force required to disintegrate it; but pound it, and comminute it as we will, we can never by these means totally overcome the attraction which constitutes its solidity; we can never so far unloose its constituent molecules as to give them freedom of motion amongst each other. The application of warmth will, however, gently and quietly loosen the tie; the ice will dissolve, and the liquid particles will yield in all directions to the slightest impulse.

§ 60. It is in consequence of the almost perfect manner in which cohesion is suspended in liquids that pressure is communicated by them in all directions alike. Solid bodies gravitate in masses, and exert no lateral pressure; but the particles of fluids gravitate independently of each other, and press against each other in every direction, not only downwards, but upwards and sideways. It is in consequence of this lateral pressure that water flows from an opening in the side of a vessel in which it is contained; and the lateral pressure is the result of the downward pressure of the liquid above, and exactly equal to it: consequently, the lower the orifice is made in the vessel the greater will be the velocity of the water running out of it, and the further it will be projected from it (14). It is the same pressure acting upwards which occasions water, when

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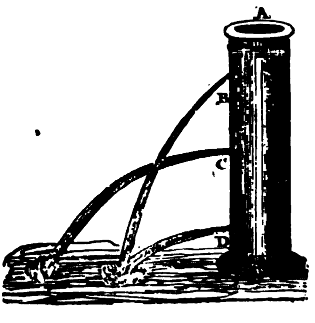
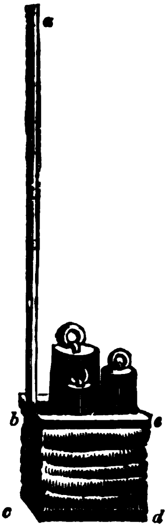


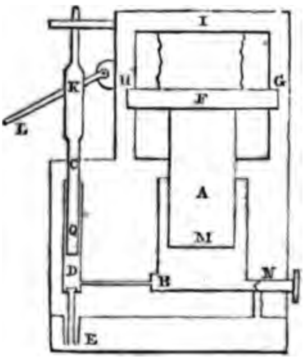
(14) If D be a hole made in the side of the vessel of water, A, the water at D would only be pressed by the simple weight of the perpendicular column of water from A to D; but when the orifice at D is open, and the water permitted to spout out, its motion throws its whole column into action, and it will now press upon and discharge the water from D, with the same force as if the water had been a solid descending from A to D, which would be as the square root of the height A D: and, for the same reason, water issuing from other orifices, C and B, would run in quantities and velocities proportionate to the square root of their depths below the surface of the fluid. If D be four times as deep below the surface, A, as B, it will discharge twice the quantity of water which can flow from B in the same time; and if D were nine times the depth of B, three times the quantity would issue from it.

poured into one leg of a siphon, to rise to the same height in the other (15).

§ 61. But it is not only the pressure of their own particles which is thus equally distributed throughout masses of fluids, but external force or pressure is communicated in the same way. In the Bramah's press an immense accumulation of force is brought to bear upon a particular point by pressure applied to a small column of water, reacting upon a larger mass placed under the surface of a moveable piston in a large barrel (16).



(15) This figure represents the arrangement of an experiment which commonly goes by the name of the Hydrostatical Paradox. *a b* is a narrow tube connected with the extensible vessel, *c d e*; when water is poured into the tube, the weight upon the surface will be raised by the pressure of the column of water in the tube, which will act with the same force as a column of water of the same height, whose base would have an equal area with the surface of the vessel.

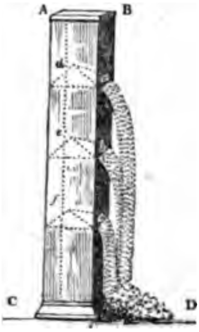


(16) This figure represents a section of the press. D is a small but strong pump-barrel, fitted with the piston, Q, which is worked by the lever K L. By this pump water is raised from the reservoir, E, and injected under the large piston, A, M, fitting tightly in the barrel, H, N, and to which the press-plate, F, is attached; any force which is exerted upon the piston Q, is multiplied upon the piston, M, in direct proportion of the area of the latter to the former, and any substance placed between the plates I F, thus becomes violently compressed. The pressure is immediately relieved by turning the screw N, by which the water is allowed to flow back into the reservoir.

§ 62. That imperfect destruction of cohesion, which is effected by mechanical force, is curiously contrasted with its perfect suspension by heat, by comparing this equal pressure of liquids with that of sand, or some other finely disintegrated solid. If we pour sand into one leg of an inverted siphon it will not mount in the other, and will even extend a very little way into the horizontal part. Whatever pressure be given to its upper surface will exert no influence on the issue below. A half-hundred weight placed upon it will produce no difference. The weight is not merely supported upon the base of the column, as in the case of a solid, but by the sides of the containing tube. The lateral pressure, however, does not vary with the height, as in the case of a liquid; but sand will flow out of lateral apertures made in a box, in which it is contained, with equal velocity, whatever may be the height of the column within (17).

Single grains of sand, placed upon a flat surface, do not begin to roll until it is inclined between 30° and 40°, and this is the angle at which the pressure is exerted, when this motion is resisted. The angle formed by a heap of shot or peas is 30°, and the weight of a pyramid, whose sides are inclined at this angle is alone supported by the base, whatever may be the height of the column confined above it (18).

A very simple mode of showing this effect is, to take an open tin tube of any length, an inch in diameter, and to press a piece of thin paper, with the edges moistened, against the end of it, letting it adhere simply by such moisture; then, placing the tube upright, with that end upon a table, to fill it with sand, and afterwards gradually to raise it; whatever the weight of the tube and its contents, it may be carried anywhere in that position, although the paper bottom adheres but very slightly.



(17) A B C D represents a box filled with pure dry sand: if equal slits, *a b c*, be made in one of its sides, equal quantities will flow from them in equal times and will be projected to equal distances, notwithstanding the difference in the heights. This figure should be compared with figure 14, which represents the flowing of water under similar circumstances.

(18) If sand be allowed to fall from a height, C, upon a flat surface, A B, it will form at first the small cone, 1 1, which will increase to 2 2, 3 3,

§ 63. After the cohesion of ice has been suspended, a further accession of heat will convert the liquid water into a highly-elastic aëriform fluid, which is commonly known by the name of steam. The repulsive force acquires the ascendency; the constituent particles tend to fly from one another, and are only restrained by the pressure of that surrounding atmosphere which regulates the elasticity of all aëriform matter which is not insulated from its action. The progress of this change of state is not so obvious and familiar as the preceding, but it is easily illustrated by experiment. If we take a glass tube blown at one end into a bulb, and fit it with a leathern piston fixed to a hollow rod, the bore of which is capable of being closed with a screw, and cause a little water to boil in it under the piston; steam will presently issue with some force from the passage in the rod, which is to be left open for the purpose of giving it vent. Upon closing this passage, the elastic force of the steam will accumulate till it forces the piston to the top of the tube (19). This force may be instantly annihilated by removing the bulb from the source of heat, and blowing upon the tube; the aëriform water will resume the liquid state, and the pressure of the air upon the upper side of the piston being no longer counteracted by the elasticity of the steam on its under side, it will be forced down to the bottom of the tube. A fresh application of heat will restore the elastic force; it will again be forced up; and by a repetition of the process this little model of a steam-engine may be kept in action. Why

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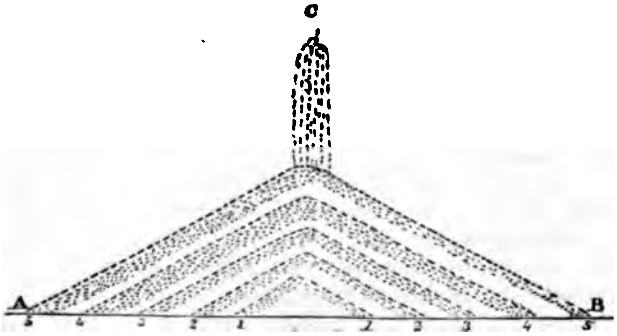
&c., and as it rolls down will always maintain a conical surface whose inclination to the base is about 30°. The direction of the pressure of the



sand, in the box A B C D, fig. 17, and its equality, is represented by the pyramids, *d e f.*

(19) *a* represents the glass-tube, with the bulb at its lower end;

the processes of liquefaction and vaporization take place slowly and gradually,—why a mass of ice does not instantly melt, or any body of water flash into steam upon reaching the proper temperatures, will be shown when we come to treat of the laws of that extraordinary agent, HEAT, upon which these transformations depend.

§ 64. There is great reason to suppose that all unorganized matter may be susceptible of similar changes of state;—that every solid might assume the state of a liquid, and of an aëriform body; and that every air, or gaseous body, might be reduced to the liquid, and even solid, state. Our command over the forces of nature does not extend so far at present, but the phenomena which we will further examine are so general as to justify the conclusion that they are universal.

§ 65. With regard to solids, we distinguish several properties as modified results of the force of cohesion; namely, hardness; elasticity; brittleness; malleability; ductility; and compressibility.

§ 66. The relative *hardness* of a body is determined by its capability of scratching, or being scratched by other bodies. It has no relation whatever to density, for lead, which may be easily scratched by the nail, has a specific gravity more than three times that of a diamond, the hardest substance in nature; neither is it connected with

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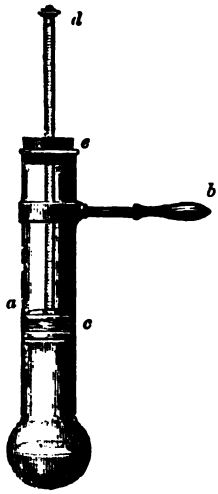

b is the handle by which it is held; *c* is the piston, the rod of which passes through a cork at *e*.

tenacity and brittleness, for iron is easily scratched by glass. It is needless, however, to dwell upon a property which every one is in the habit of appreciating.

§ 67. *Elasticity* is that property which we have already exemplified by the flexure of a spring, and the torsion of a thread of glass; in consequence of which the particles of a solid yield to a certain extent when force is applied to them, but immediately fly back to their original position when the disturbing power is withdrawn. Elastic bodies vary much in the extent to which they yield without breaking, and in the degree of perfection with which, after the displacement of their particles, they return to their former state. A piece of caoutchouc, or Indian rubber, is very elastic, but not perfectly so, for it becomes permanently elongated by stretching. Glass, on the contrary, is perfectly elastic, for it will retain no permanent bend: when drawn into a fine thread it may be twisted round upon its axis many times without breaking; and when set free, always returns to the point from which it set out.

§ 68. *Brittleness* consists in the facility with which a disrupture takes place amongst the particles of a solid, from a slight change of position amongst them, beyond the limits of their elasticity. It belongs to most hard and elastic bodies, and may be exemplified by glass and steel.

§ 69. *Malleability* is the capability of extension into thin leaves, by hammering. It exists, in different degrees of perfection, amongst the metals. Gold may in this way be beat into such thin leaves that 282,000 of them would only make up together the thickness of an inch. Silver and copper are likewise capable of being extended into very thin leaves; and tin and lead into foil, necessarily of much greater thickness.

§ 70. *Ductility*, or the capability of being drawn into thin wire, is not, as might at first be supposed, the concomitant of malleability. Iron is incapable of being beaten into thin leaves, but may be drawn into wire finer than a human hair.

§ 71. *Compressibility*. Some of the metals have their density permanently increased by mechanical force; when thus compressed, they do not spontaneously return to their former bulk.

§ 72. In liquids we have already seen that cohesion predominates to a very small degree. Their particles yield amongst each other to the slightest impulse, and communicate pressure in all directions alike. The force required to change their volume in any sensible degree is so great, that until improved means of experiment were very recently contrived, they were accounted incompressible. It has been found that by plunging a vessel of water into the sea, to a depth of 1000 fathoms, the compression is one-twentieth of the bulk; and the following table represents, according to the accurate experiments of Professor Œrsted, the amount of compression of several liquids in millionth parts of their volume, for each additional atmosphere or pressure of 15 lbs. per inch (20). After the pressure is withdrawn they return to their original bulk.

Table III. *Compression of Liquids.*

	Millionth parts, per atmosphere.
Mercury	2.65
Alcohol	21.65
Water	46.65
Ether	61.65

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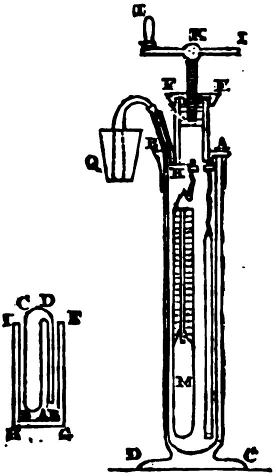
(20) A B C D represents a strong glass cylindrical vessel, to the top of which a similar cylinder of metal, A E F B, is firmly screwed, an air-tight piston moves in this, by means of a screw, K; M is a glass bottle, terminating in a fine capillary tube, open at both ends; it is graduated with great accuracy into precise fractions of the contents of the bottle. This is done by weighing the quantity of mercury which the bottle will hold, and the quantity which may be contained in an inch of the tube. In Œrsted's apparatus each inch of the tube was found to contain 80 *millionths* of the contents of the bottle. The bottle, with its scale, are introduced into the glass vessel, A B C D, which is then filled with water, and the cylinder, A E F B, firmly screwed in its place. When the piston is drawn back, water is pressed into the cylinder through the siphon, B, connected with the vessel Q; when it is full, the communication with the siphon is closed by a cock; pressure may then be communicated to the contents of the vessel, by the screw, K, and lever, I I. The pressure within and without the bottle will be the same. The amount is measured by a gauge, N, placed by the side of the bottle,



§ 73. Certain differences may be observed in the still remaining cohesion of different liquids. Thus we distinguish *viscous* and *limpid* liquids.

Viscosity is that quality which renders the homogeneous particles less moveable amongst one another, and is the direct opposite to limpidity. It is a modification of cohesion somewhat analogous to malleability in solids.

It may be regarded as a kind of approach to the solid state, but is distinguished from mere cohesion; for if two drops of a viscous fluid are brought into contact with one another, they run together with much less velocity than two drops of a more perfect fluid.

Oil and syrup are specimens of viscous; mercury, and spirits of wine, of limpid liquids. Some solids, like glass, become viscous by heat, in their passage to complete liquidity; whilst others, like water, become perfectly limpid at once.

§ 74. Aëriform fluids are commonly and conveniently distinguished into two classes: namely, *vapours* and *gases*. Steam will illustrate the first, and the air which surrounds us the second. We

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consisting of a glass tube closed at the top, and open at bottom, and divided into equal parts; it contains a small portion of air, and is placed in an inverted position. When the pressure is applied, the air is compressed continually into a less and less bulk; the diminution of its volume being precisely proportioned to the pressure, and is measured upon the scale.

The water in the tube of the bottle is separated from the water in the cylinder, by which the pressure is communicated by a little air contained in a small funnel inverted over its upper end, which also contains a bubble of air; so that there always intervenes between the exterior and interior water a column of compressed water, which may easily be seen from without. By a similar apparatus, constructed of metal, to enable it to bear a higher pressure, Professor Œrsted measured the compressions of air to 65 atmospheres. For this purpose, a small index, fixed by a hair-spring, was placed in the upright gauge, which being pressed forward by a column of mercury, was left at the extreme point to which the liquid was forced, and thus registered the pressure. The amount of the compression was also registered, by the simple apparatus, H I F G, which is an open vessel containing mercury, in which is placed a glass vessel, A B C D E, drawn out into a slender tube, D E, and turned down, as shown in the figure. This vessel is filled with air, and placed in the receiver, and when pressure is applied, the effect is to drive the mercury up the tube E D, and into the vessel C B, compressing the air above it, and falling to the bottom of that vessel. The volume of this metal being added to that which was contained in the tube, will equal the volume by which the air was compressed during the experiment.

have seen that the slightest abstraction of heat proportionately reduces the elasticity of steam, and condenses it into the liquid state. The slightest increase of pressure beyond the force of its own elasticity will produce the same effect, unless a simultaneous increase of heat enable it to sustain it; but the greatest reduction of heat which art can produce (and its command in this respect is considerable), and the greatest pressure which can be applied, have never yet succeeded in bringing the particles of atmospheric air within the verge of cohesive attraction.

§ 75. Other gases, however, which but lately were considered to be as permanent as atmospheric air, have yielded to the ingenious manipulation of Dr. Faraday. His method consists in generating the gas in a confined space, when, from the narrow compass into which it is obliged to pack itself, the mutual compression of its own particles is so great that they come within the limits of their self-attractive force, and assume the liquid state. It is true that the elastic force increases as the compression; but the energy of the cohesive force, when its limit is attained, in a much higher degree;—not in the inverse proportion, that is, to the distances of the particles from one another, but as the squares or, probably, some higher power of the distances. Different gases yield to different degrees of compression; a pressure equivalent to two atmospheres is sufficient to produce the liquefaction of some, while carbonic acid requires thirty-five atmospheres, or a pressure of 525lbs. upon the square inch of surface; and although experiment has yet failed to produce the effect, fair analogy justifies the hypothesis of geologists, that atmospheric air may exist in the liquid state, in cavities of the compressed stratā of the globe.

§ 76. The difference between a vapour and a gas, it may be observed, is one of degree and not of kind, for the aëriform fluid, which in the compressed tube floats above the liquefied portion of the gas, is strictly the vapour of the liquid portion, and is influenced by precisely the same circumstances as the vapours of liquids, which exist as liquids under atmospheric pressure alone.

§ 77. There are one or two other circumstances attending the reaction of the antagonist forces of homogeneous attraction and repulsion which ought to arrest our attention. When a liquid is about to assume the solid state, if the heat be very slowly withdrawn, and it pass very gradually under the influence of cohesion, the particles do not rush together into a confused *amorphous* mass, but sometimes build themselves up into geometrical solids of the greatest beauty and symmetry. This phenomenon is familiar to us in the freezing of water,—so familiar that it does not excite half the attention and admiration which it ought to inspire: we see it in the ice which forms upon our windows in the winter's night,—in the hoar-frost upon the trees, and in the construction of flakes of snow. The seemingly endless variety of figures which these substances present is limited by certain laws, and the lines which bound them form amongst themselves no angles but those of 30° 60° and 120°. If we melt a mass of sulphur, or of the metal bismuth, in an earthen pot, and when it has slowly cooled, so as just to become crusted over, pierce the crust, and allow the liquid portion to flow out, we shall find the cavity of the latter studded with beautiful cubic forms which the most skilful carver could not rival (21), and that of the former with no less beautiful six-sided prisms and needles.

These forms are denominated *crystals*, and the process is called *crystallization*.

§ 78. The assumption of the solid form is often attended with the exertion of an uncontrollable expansive or repulsive force; proving again the porosity of solids, the particles of which the prejudices derived from common observation would induce us to believe were in the closest contact.

This phenomenon cannot be better exemplified than in the passage of water into ice. Indeed, the common experience of a hard winter places the proof before us, in the bursting of pipes in which water is carelessly allowed to freeze: and if we take

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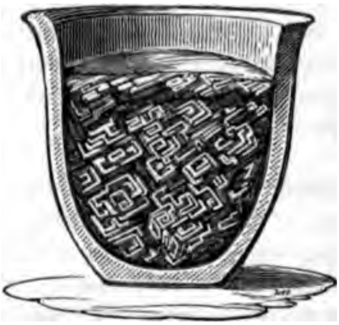

(21) In this figure is represented the section of a crucible containing bismuth, from which the liquid portion has been allowed to flow out at the moment of the consolidation of the remainder.

a small piece of a gun-barrel, securely plugged at one extremity, and closely fitted at the other with a screw, fill it with water which has been boiled to exclude the air, carefully close it, and place it in a situation where it may freeze, at the moment of solidification the barrel will burst with a considerable report.

The specific gravity of ice, compared with water, is 0.92.

Iron, likewise, enlarges its bulk at the moment of solidification, and hence the particular sharpness of casts which are made with it, the expansive force pressing it into the minutest crevices of the mould.

Other liquids, on the other hand, contract in bulk at the moment of congelation, of which mercury is an example.

§ 79. HETEROGENEOUS ADHESION.

We come now to the contemplation of the action and reaction upon each other of particles of matter of totally different kinds,—of different essence and sensible properties: and the first force with which such particles have been endowed we may usefully distinguish from cohesion, or homogeneous attraction (to which it is opposed), by the title of *adhesion*, or *heterogeneous attraction:* we have already exemplified it by the wetting of glass by water.

We trace it in matter in all its physical states; *i. e.* whatever the antecedent adjustment of the forces of homogeneous attraction and repulsion may be: but it exists in different degrees between different bodies; and, possibly, between some bodies does not exist at all. A polished blade of iron is capable of being wetted by water, not, however, in so perfect a manner as glass; but to neither of these substances will mercury adhere. It would, nevertheless, be too hasty a conclusion to infer from this observation that there were no adhesive attraction between the particles of glass, or iron, and mercury; the attractive force may exist, but in these instances the homogeneous attraction of the particles of the liquid may be superior to it, and prevent its efficiency. A perfectly clean surface of platinum is capable of being completely wetted by mercury; but the thin film of extraneous matters which commonly adheres to this metal in its ordinary state, effectually prevents their mutual action.

Guyton de Morveau measured the force with which different metals adhered to the surface of mercury, by suspending equal plates from one of the arms of a balance, and ascertaining at the other the weight which was in each case required to separate them. He employed fresh mercury in each experiment, and the following table exhibits his results:—

TABLE IV. *Adhesion of Mercury.*

	Grs.		Grs.
Gold	446	Zinc	204
Silver	429	Copper	142
Tin	418	Antimony	126
Lead	397	Iron	115
Bismuth	372	Cobalt	8

§ 80. The action of cements, in permanently fixing the surfaces of solids together, is dependent upon this force. For this purpose some substance in a soft or liquid state is interposed, which is capable itself of solidifying and drawing the surfaces together by this species of attraction. In this way wood may be attached by gelatine, or glue; porcelain, by albumen, or white of egg, and lime; and bricks, by mortar; so that the adhesion of the surfaces of junction may offer even greater resistance to disruptive force than the cohesion of any other part.

§ 81. The heterogeneous adhesion of solids to each other is also of the greatest practical importance when it assumes the form of friction, that is, of superficial opposition to mechanical force, or the motion of two bodies in contact (§ 58). All other things being equal, friction is less between surfaces of dissimilar matter than between those of the same matter: thus the resistance of iron, moving upon iron, is expressed in terms of the pressure by the fraction $\frac{1}{3.5}$, while that of iron upon copper is only $\frac{1}{6}$. The interposition of substances whose force of cohesion is small, such as plumbago, or grease, greatly decreases friction: thus the resistance of iron upon iron is diminished to $\frac{1}{10}$th by the application of tallow; and of iron upon copper to $\frac{1}{11}$th. The complete investigation of this opposition of forces belongs to the science of mechanics; it would, however, have been a defect in this preparatory view, not to have indicated an antagonism of forces on which we are dependent in almost every action of our lives. It is friction which prevents our feet slipping back every time we attempt to advance a step; and those who have attempted to walk upon polished ice well know how to appreciate the passive resistance of heterogeneous adhesion.

§ 82. A beautiful example of the adjustments which take place of the two antagonist forces of homogeneous cohesion and heterogeneous adhesion, is afforded by the phenomena of, what is termed, *capillary attraction.* The simplest case of this action arises when we dip a glass tube of very fine bore (hence termed a *capillary* tube) into a liquid which is capable of wetting it; upon attentively examining the appearances presented by such an arrangement, we shall find that the liquid rises in the tube to a certain height above the usual level, and assumes a concave surface at its upper extremity. We shall also observe, that on the exterior surface of the tube, as well as where it is in contact with the containing vessel, the liquid will stand above the general surface.

Now we have here three forces concerned;—the force of gravitation, by the action of which upon the moveable particles of the liquid the general level of the mass is maintained; the interior force of homogeneous attraction, drawing the similar particles together, and resisting any force which may tend to separate them; and the exterior force of heterogeneous attraction between the solid and the liquid. The latter has power to draw up the included liquid (which is cut off by the glass from the action of the homogeneous attraction of the surrounding mass) against the action of the two former forces to a point at which they are all in *equilibrio;* and this power increases in some high ratio inversely as the distance; so that the nearer the approximation of the active particles, the greater the elevation. This is not only shown by the gradual upward curve of the liquid, as its distance from the solid decreases, but may be demonstrated by varying the size of the tube; when the rise of the liquid will be found to increase rapidly as the diameter decreases.

It is in consequence of the concave surface of the liquid thus produced, that the particles are drawn inwards by their own attraction with less force than when the surface is plane, and the consequent diminution of pressure from without, inwards, is made up by an additional column of the liquid.

The same action may be strikingly illustrated by dipping the ends of two plates of glass in coloured water, at a very small and gradually decreasing distance from each other; the water will rise between them, and the force increasing as the distance diminishes, will be shown by the *hyperbolic curve* of the upper surface, the heights of the different points of the surface of the water being inversely proportional to the distances from the angle, a property of the curve which is thus called by mathematicians.

§ 83. If, on the other hand, the liquid into which the capillary tube is plunged, be incapable of wetting it, that is to say, if the homogeneous attractive force should be superior to the heterogeneous attractive force, a different order of phenomena will arise, but illustrative of the same principles. A fine glass tube, thus immersed into mercury, will exhibit a depression of the internal column of liquid below the general level; the upper surface will be convex instead of concave; and at the point of contact, both of the exterior of the tube and of the surface of the containing vessel, the liquid will be depressed. The forces concerned in the phenomena are the same as before, but now the homogeneous attraction has the superiority. The mercury within the tube is cut off by the inactive surface of the glass from the homogeneous attraction of the surrounding mass; its own self-attractive force, therefore, acts as from its centre, drawing its particles together, and causing them to assume more or less of a globular aggregation, according to the same law which determines the spheroidal form of a suspended drop of liquid. The increase of pressure from without, inwards, which is the consequence of the surface being convex instead of plane, is balanced by a diminution of the column. The amount of this action is also inversely proportionate to the diameter of the tube (22).

The following table exhibits the amount of depression in tubes of different diameters. In one column is included the result of experiments when the mercury has been boiled in the tube; in another, the results after boiling. In the first case a thin layer of air coats the tube; in the second, this is expelled.

TABLE V. *Capillary Depression of Mercury.*

Diameter of tube. In.	Unboiled. In.	Boiled. In.
0.60	0.005	0.002
0.50	0.007	0.003
0.45	0.010	0.005
0.40	0.011	0.007
0.35	0.019	0.010
0.30	0.028	0.014
0.25	0.040	0.020
0.20	0.059	0.029
0.15	0.088	0.044
0.10	0.142	0.070

(22.) C D represents a capillary tube, immersed in a liquid capable of wetting it, in the vessel *e f g h*. The liquid stands at a considerable height above the general level of the liquid, and is also drawn up by the sides of the containing vessel, and the exterior surface of the tube, so as to form a curve between them. The form of the surface of the liquid within the tube is shown at *i k l m*. A B represents a capillary

§ 84. Capillary action is of great importance in many natural and artificial arrangements; and as familiar instances of it, we may refer to the absorption of water by a piece of sponge, and to the beautiful manner in which the flame of a lamp or a candle is supplied with the liquid combustible by its ascent in the wick. The parallel interstices of a bundle of small wires will perform this office as well as the fibres of cotton, which are commonly employed, and being incombustible, may be perpetually used, provided they be kept clean. The natural pores of vegetable bodies are also well adapted to the spontaneous ascent of liquids, and it is probable that the motion of the sap of plants is considerably dependent upon this power. The fact may be pleasingly exemplified by dipping one end of a piece of cane into spirits of turpentine, which will rise to the other, and may be ignited.

It is by this force, again, that water is imbibed by the porous materials of the earth's surface, and moisture distributed in due proportions to the roots of vegetables. The amelioration of soils by culture is brought about by changes effected in them in this respect; and the influence of differences, even in their original constitution, may be traced in the superior verdure of chalk hills over those of sand or gravel.

§ 85. The action of filtration, to which the chemist is so frequently obliged to recur, is also dependent upon capillary action. The pores of the filter become wetted by the liquid, and transmit it to the under surface by a force of *adhesion* which is independent of the pressure. When once it has penetrated it collects into drops, by the force of *cohesion*, which fall from the force of gravity. Not only may solids be thus separated from liquids, but liquids which imperfectly mix, from each other. For this purpose the filter must be previously wetted with the liquid which it is

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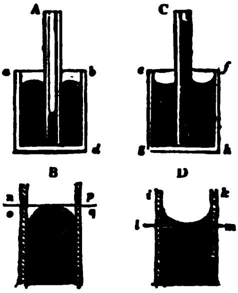

tube immersed in a liquid which is incapable of wetting it. The liquid is here seen depressed below the general level, and its surface in the vessel, *a b c d*, is curved from the depression which also takes place at the points of contact at its surface, and the exterior surface of the tube. The form of the surface within the tube is shown at *n o p q*.

intended to transmit, when that alone will pass, and the other be rejected. In this manner spirits of turpentine and water may be parted from each other.

§ 86. Few persons, perhaps, are aware of the prodigious amount of the force which may thus be called into action, and which may be measured by the opposition which it is capable of overcoming. If a dry plug of wood be tightly fitted into one end of a stout tube of glass, or porcelain, and a projecting portion be allowed just to dip into water, the wood will swell with such force, by the intrusion of the liquid into its pores, as to burst the tube, though capable of resisting a pressure of more than 700lbs. on the square inch. This power is turned to an economical account in parts of Germany and France, for separating blocks from the solid rock, for mill-stones. Holes are bored in its substance, into which wedges of dry wood are tightly driven, and when these are exposed to moisture they swell, from the capillary action, and effectually split it in the direction in which they have been placed.

§ 87. The same kind of attraction and superficial action takes place between solids and aëriform bodies, although not so open to common observation: but an easy experiment will illustrate the fact. Take some of the fine dust of magnesia, and sift it carefully upon the surface of some water, in a tall glass jar, and it will presently become wetted by the liquid, and sink to the bottom in consequence of its specific gravity being something more than twice as great. Take, again, some iron filings, and sift them in the same manner upon the surface of water, and although their specific gravity is nearly four times greater than that of magnesia, they will float upon the top. A stratum of considerable thickness of the metal may thus be laid upon the liquid, which at length will sink in considerable masses, when it may be seen that they had been previously buoyed up by the adhesion of particles of air, which their accumulated weight will even carry to the bottom with them. The surface of each fragment of metal had been (we cannot, perhaps, say *wetted*, but) *enfilmed* with the gaseous matter, which prevented it from being wetted by the water; in the case of the magnesia, its attraction for the air was less, and, consequently, it was more readily displaced by the water.

The force of adhesion of air to glass is very considerable, and requires particular attention in the construction of barometers. In filling a glass tube with clean mercury, it is easily seen how pertinaciously small bubbles adhere to its sides: many of these may be swept away, by causing a large bubble to pass several times from top to bottom, by the inclination of the tube; but it will still remain coated throughout with a thin film, which can only be removed by boiling the mercury in it. After this process has been performed, the air will still creep down between the sides of the mercury and the glass, which do not adhere together, and ultimately steal up the whole length of the column into the vacuum. The gradual deterioration of barometers in this way, may, however, be entirely prevented by welding a ring of platinum to the bottom of the tube, and wetting it with the mercury. Close contact of the liquid and the tube is thus secured, and the welding of the platinum to the hot glass is another instance of strong heterogeneous adhesion.*

§ 88. Some porous solids are capable of absorbing and retaining large quantities of gaseous matter; and newly-burned charcoal has the property of taking up the following volumes of the different gases, its own volume being taken as 1.

TABLE VI. *Absorption of Gases by Charcoal.*

Ammonia . . .	90	Bi-carb. hydrogen .	35
Muriatic acid . .	85	Carbonic oxide .	9.4
Sulphurous acid .	65	Oxygen . . .	9.2
Sulphuretted hydrogen	55	Nitrogen . .	7.5
Nitrous oxide . .	40	Carbt. hydrogen .	5
Carbonic acid . .	35	Hydrogen . .	1.7

It will appear from those results, compared with others hereafter to be stated, that those gases which are the most readily condensible, by pressure, into liquids, yield most readily to the force of heterogeneous adhesion. When charcoal already saturated with any one gas, is put into another, it gives out a portion of the gas already absorbed, and takes up a portion of the new gas.

Aqueous vapour is also very greedily imbibed by newly-burned charcoal, some kinds of which will take up as much as 18 per cent. of their weight by a week's exposure to the air.

Though charcoal possesses this property in a very eminent degree, it is by no means the only substance whose pores exert the force of heterogeneous adhesion. Certain animal and vegetable textures absorb aqueous vapour so readily and regularly, that their changes of dimensions which ensue have been taken as measures of the amount of vapour existing in the atmosphere to which they have been exposed. Thus, the untwisting of a piece of catgut, or the beard of the wild oat, the elongation of a thin slice of whalebone, all afford good *hygroscopes*, or indications of the state of the air, with regard to moisture; and the elongation or contraction of a human hair, properly prepared, is still observed at the Paris Observatory, as a *hygrometer*, although the observations cannot be relied upon, and better and accurate methods have been devised for determining a point of great importance to science (23).

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* DANIELL's *Meteorological Essays*, Second Ed. p. 577.

All these substances give up the moisture which they have imbibed when exposed to a dry atmosphere, and return more or less accurately to their original dimensions.

§ 89. The adhesion of gaseous matter to liquids is demonstrated every time we pour water from one vessel into another; large quantities of air, strongly attached to its surface, are carried by the momentum of the falling mass below the surface, and becoming more elastic from the compression, detach themselves, and rise

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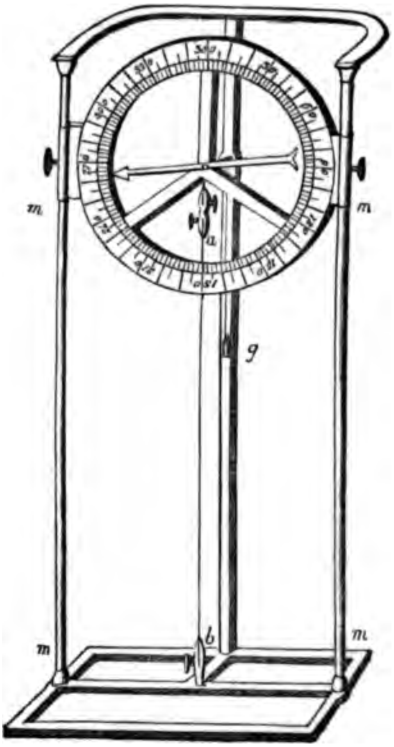


(23) This figure represents the celebrated hygrometer of De Saussure. The hair, *a b*, is freed from all unctuosity by being steeped in ley, and is kept in a state of equable distension by means of a small weight, *g*, which is suspended from the opposite side of the axis of the index. The hair is fastened by two nippers at *a* and *b*; the point of extreme dryness is determined by placing the instrument under a receiver, in the presence of some absorbent substance, as dry caustic alkali; when the hair acquires its minimum of length, it is then introduced into a receiver containing water, by which the air is kept saturated with vapour; its greatest elongation is marked upon the circle, and the intermediate space between the two points divided into degrees.

again in a stream of bubbles. We see this process upon an immense scale in natural falls of water, where the foam and dashing of the spray is evidence of the power of the escaping air. In certain situations advantage has been taken of this perpetual supply, and the air being received into cylinders in this state of compression, is applied to the supply of blast furnaces, for the working of metals.

§ 90. It is not only by this superficial action that air becomes attached to water, but by the force of adhesion it is drawn, as it were, into its pores, and is made to distribute itself equally through its mass, however deep. This aëration of water is one of the most important processes in nature. It takes place quietly and invisibly; but by this still, unobserved operation, the countless hosts of the subaqueous creation, both animal and vegetable, are supplied with the vital air, upon which their existence depends. If we take a quantity of fresh boiled water, place it in a glass vessel, under the receiver of an air-pump, and exhaust the air, it will remain perfectly transparent, and unagitated, till the pressure is so far reduced as to enable it to boil at the atmospheric temperature; but if we allow a portion of the same boiled water to remain in contact with the air for some hours, and afterwards place it under the receiver, almost from the first stroke of the pump we shall find bubbles of air forming in its mass, the greatest part of which will be attracted to the surface of the glass, and will there adhere, till increasing in size they finally make their escape. This air may properly be said to have been *dissolved* by the water; and thus we are led to consider the processes of *solution* and *mixture*, as instances of the force of adhesion; although they are commonly referred to the action of the higher force of chemical affinity.

§ 91. In seeking out the laws which limit these actions, let us first return to the mutual action of liquids and solids.—We have seen that when a piece of clean platinum is dipped into mercury, the force of adhesion between the two metals is sufficient to overcome the cohesion of the liquid which thus adheres to the solid, and wets it. If for a plate of platinum we substitute one of tin, or lead, the same effect will be produced, and either metal will be immediately wetted by the quicksilver; but if we now leave them immersed in the liquid, a further effect will be produced, and the force of adhesion will be so strong as not only to overcome the feeble cohesion of the liquid, but the strong homogeneous attraction of the solid itself: the process of solution will take place; the solid will be *dissolved* in the liquid.

Let us now select a more familiar instance:—a lump of loaf-sugar, just immersed in water by one small point of contact, will quickly draw the liquid up into its pores, by capillary action; but the force of adhesion proceeding beyond this will speedily break down the solid texture, which will disappear in the water. We may vary the illustration with any soluble salt. We may judge of the energy of the force which is thus called into action, gentle as is the process, by estimating that which it overcomes, namely, the cohesion of the solid, by the effort which we must make to break its mass. Whatever tends to diminish the antagonist force promotes and hastens the process of solution; and every one knows from common experience that the mechanical pounding or breaking of a lump of sugar or salt will considerably facilitate its solution. We have seen the facility with which glass becomes wetted with water; if we diminish its cohesion by mechanical force, a portion of it will even be dissolved by the liquid; and upon placing some very finely pulverized flint glass upon turmeric paper, and wetting it, the yellow colour of the paper will be turned to brown by the action of the solution.

§ 92. The action of a solvent upon a solid is, moreover, limited by its cohesion: when the *homogeneous* and *heterogeneous* forces are exactly balanced in the solution, the solvent is said to be *saturated.* With regard to water, the point of *saturation* for different bodies, even of the same class, varies very much; thus at ordinary atmospheric temperatures, an ounce of distilled water will dissolve half its weight of sulphate of ammonia; one-third of its weight of sulphate of soda; one-sixteenth of sulphate of potassa; and not more than one five-hundredth of sulphate of lime. Water, however, which is saturated with one salt, will still be capable of dissolving another.

§ 93. The mechanical disruption of a solid, even by the finest levigation, is, as we have seen (§ 62), but a very imperfect mode of diminishing the force of cohesion; the finest conceivable particles which can thus be detached, consist, probably, of a countless multitude of its ultimate atoms, which are still closely bound together by homogeneous attraction; but by the application of heat we have it in our power to counteract the latter force, by a repulsion of the like intimate nature; and by so doing we increase the effective antagonist force of heterogeneous attraction. The action of a solvent upon a solid is, therefore, much increased by raising its temperature. Water may thus be saturated with a salt, at the common temperature of the atmosphere; and if heat be afterwards applied, will dissolve an additional quantity; if the solution be then allowed to cool, the attraction of cohesion will resume its ascendency, and the additional portion of the salt will be deposited in a regular solid form.

There are, however, two or three remarkable exceptions to this general law. Water, at the temperature of 32°, will dissolve $\frac{1}{656}$th of its weight of lime; at a temperature of 60°, it will take up no more than $\frac{1}{780}$th; and when boiling only $\frac{1}{1280}$th; so that when lime-water is boiled, a portion of the lime is precipitated, or aggregated into small crystalline grains. The solubility of sulphate of soda in water also follows a singular law: after having increased rapidly to the temperature of 92°, where it is at its maximum, it diminishes to 215°, at which temperature the salt is nearly of the same solubility as at 87°. The seleniate of soda is another salt which presents an anomaly of the same nature. Exceptions to general laws of this kind, although not understood, are facts of extreme interest, and generally present the commencement of a clue, by following which we may be led further in the labyrinths of natural knowledge.

§ 94. As the force of heterogeneous adhesion is thus capable of overcoming the force of homogeneous attraction, so is it capable of restraining and keeping down the force of homogeneous repulsion; and gases are susceptible of solution in liquids; and as the point of solution of solids is determined by the antagonist force of cohesion, so is a liquid said to be saturated with a gas when the forces of heterogeneous adhesion and self-repulsion are exactly balanced. We have just seen that atmospheric air may be thus united with water, but other kinds of aëriform matter are capable of this union to a much greater extent. Water will dissolve its own bulk of carbonic acid, whatever its elasticity may be, provided an equivalent amount of pressure be maintained upon its surface. Soda-water is thus kept ready for immediate effervescence by the mechanical compression of this acid upon it, from which it begins to make its escape the moment the pressure is relieved. By heating this solution the whole of the air may be expelled; for heat, of course, increases the repulsive force, and enables it to overcome that of adhesion.

§ 95. But there are other gases which being once taken up by water are not capable of being again separated by any increase of temperature; the force of adhesion between them is so strong, that they remain united when both are in the self-repulsive state. Thus muriatic acid, or ammoniacal gases, are absorbed by water with a rapidity which is quite immeasurable, and when the solutions are of a certain strength may be distilled without change; they rise together in the elastic form, and are again condensed by cold.

§ 96. This will aptly introduce to our notice the exertion of this force by bodies in the same physical state, as the action of liquids upon liquids and gases upon airs or vapours. Such combinations are termed mixtures, and, unlike solutions, are unlimited by any antagonist force either of attraction or repulsion.

Some liquids, however, are incapable of this incorporation or mixture: thus oil and water may be mechanically mingled together by agitation; but, as every one knows, spontaneously separate again in the completest manner. Here we may suppose that the forces of cohesion and gravity which both oppose adhesion, are superior to the latter. Some few liquids mix together in a very minute proportion of one of them, as ether and water. If these two liquids be agitated together, by far the largest portion of the former will separate from the latter, and float upon its surface. This is, in fact, a case of solution, the point of saturation of which is determined by cohesion and gravity: most liquids, however, mix together, and particularly with water, in the most perfect manner, in all conceivable proportions, and against the greatest differences of specific gravity: thus, a drop of oil of vitriol, or of alcohol, will become perfectly diffused through a gallon of water, or a drop of water through a gallon of vitriol or spirit. The specific gravity of sulphuric acid is almost double that of water, and yet the difference, combined with its remaining cohesion and that of the water, is not sufficient to separate the two. The progress of the mixture may be shown in a very interesting manner by colouring some water with some vegetable blue, and carefully pouring it, by means of a small tube, upon the surface of the acid, in a tall glass jar: at the point of contact of the two liquids, and to a small height above, the blue water will be immediately reddened by the acid; but if the experiment be carefully made, the colour of the great bulk will be unaffected, and the jar will exhibit three perfectly distinct strata, of colourless acid below, of mixed acid and water of a red colour in the middle, and on the top the blue unmixed water. In this state of things the process will proceed; the heavy acid will be slowly attracted upwards, and its course will be marked by the change of colour. That the mixture is not produced or assisted by any currents in the liquids, will be manifest from the lines of junction of the different colours, which will remain perfectly sharp, well defined, and horizontal, during the progress of the experiment, which will not be complete for three or four days. A similar experiment may be made with coloured alcohol and water, and in both cases the mutual penetration will ultimately be perfect.

§ 97. We have already noticed the *statical* adjustment of the forces of homogeneous and heterogeneous attraction between a solid and liquid, in the case of capillary action; a curious and highly important dynamical effect results from the operation of the same forces in what has been denominated the process of *endosmose* and *exosmose;* in which the mutual attraction of two liquids is called into action, one of which is more capable than the other of freely wetting a porous solid which forms part of the combination.

If we dip a piece of bladder, or other animal membrane, into water, it will be wetted, and completely soaked with the liquid; but if we dip it into spirits of wine, it will superficially adhere to it, but will not be imbibed into its pores, and may be wiped off without difficulty. Take a funnel, and tie over its broad end, of three or four inches diameter, a piece of bladder, invert it, and fill it with spirits of wine, and fit to its small end a small glass-tube three or four feet in length, and then place it upon a perforated tin plate in a vessel of water, in a short time the liquid will be observed to rise in the tube; and, notwithstanding the accumulating pressure, which will be the same on the bladder as that of a column of the liquid of equal base (§ 61), it will ultimately reach the top and flow over. The first moving power is here the force of adhesion between the water and the bladder; the former penetrates the pores of the latter, and comes in contact, upon its upper surface, with the spirit, by the heterogeneous attraction of which again it is removed, and mixes with its mass. The height of the column is in some degree the measure of the force thus called into action, which, in the case under consideration, is also opposed by the difference of the specific gravities of the water and spirit. Other liquids may be substituted for the spirit, provided only there be a strong disposition in them to mix with the water; and even strong solutions of solids, as sugar, gum, &c., will determine the action of *endosmose* by their still predominant attraction for more water. The organic texture of the membrane is not necessary to the process, which will equally take place through thin plates of clay-slate and other porous substances. The *endosmose* (or flowing in) of the exterior liquid is generally accompanied by the *exosmose* (or flowing out) of the interior liquid, but to a much less extent; the difference depending upon their greater or less attraction for the interposed solid, or their capability of wetting it. Modifications of this process are of the highest importance in many of the operations of the organic portion of the creation, and the study of them promises to throw light upon many obscure points of animal and vegetable physiology.

§ 98. Aëriform bodies are capable of mixing together in the same way as liquids; and as there are no remains in their case of efficient cohesive force to oppose the force of adhesion, they are all capable of rapid diffusion through each other's masses, and there is no limit to their incorporation: there is no point of saturation. If a portion of hydrogen, which is an inflammable gas, and the lightest known ponderable substance, be confined in a strong phial, and a portion of oxygen, a supporter of combustion, and sixteen times heavier, in a similar vessel, and the two be connected together by a narrow tube, three or four feet long, the hydrogen being placed above, in the course of a short time the heavier air will be drawn up by the lighter, and the lighter drawn down by the heavier, so that a perfect and equal mixture of the two will take place, and an explosive compound will be found in both the phials; and the same property belongs to all gases. In the same way, if water be introduced into a receiver of perfectly dry air, evaporation will immediately commence, and vapour, of exactly the same tension as that which at the same temperature would rise *in vacuo*, mixes with the atmosphere. Dr. Dalton, to whose clear views upon this subject science is greatly indebted, expressed this general fact by stating, that "One gas acts as a *vacuum* with respect to another." By this he did not mean to assert that the process of diffusion takes place with the same velocity as if it were a real vacuum; because the particles of one gas he conceived afford a mechanical impediment to the progress of the other; but that the ultimate result is the same.

§ 99. The process of *endosmose*, which we have already examined in the case of liquids, is also capable of being maintained by aëriform bodies, and has been the means of throwing much light upon the diffusion of gases. We have alluded to the phenomena produced by the difference of the force of adhesion in water and alcohol to animal membranes; the same difference exists in their aëriform state: and if we place a mixture of the two liquids in a wide-mouthed vessel, closely covered with bladder, the vapour of the water will freely pass through, but not the vapour of the alcohol. As the former penetrates to the upper side it is removed by mixture with the atmospheric air, the process of evaporation proceeds, and the alcohol is ultimately left in the vessel almost in a state of purity.

If a portion of common air be confined in a wide-mouthed jar, by tying tightly over it a piece of sheet-caoutchouc, and the jar be placed under a large bell-glass filled with hydrogen gas, the hydrogen will gradually penetrate the partition, and on coming in contact with the air will mingle with it, till successive portions thus packing themselves into the confined space, will act with such elastic force upon the caoutchouc as to distend it in a globular form, and ultimately burst it. The experiment may be varied by suspending a membranous bag, such as the stomach of a rabbit, or other small animal, filled with common air, in an atmosphere of carbonic acid; the latter will penetrate to the former, and ultimately burst the bag. The *endosmose* is accompanied by an *exosmose*, as in the case of the two liquids, but the amount of the gas which passes in, so much exceeds that of the gas which passes out, that it produces the effect which has just been indicated. By the slow action of the same forces, hydrogen gas, confined in a bell-jar which has a crack in its side, will gradually make its escape; and any gas placed under a glass receiver, surrounded by quicksilver, will slowly diffuse itself into the atmosphere, by creeping through the interval between the metal and the glass, which do not perfectly adhere together.

§ 100. The law of the diffusion of gases has been most beautifully determined by Professor Graham, by means of what he has named a *diffusion-tube*, which is simply a graduated tube closed at one end by plaster of Paris, or some other porous substance. When such a tube is carefully filled over water, with hydrogen gas for instance, the closed end being kept dry, the hydrogen will immediately begin to flow through the pores, and diffuse itself in the air, and that with such velocity as to draw up after it a column of water of considerable height. The rise of the water commences immediately, and forms a very striking experiment. In a tube fourteen inches long it will ascend six or eight inches in as many minutes. The atmospheric air tends also to pass in the opposite direction, and as the elasticity of the air in the tube decreases it is gradually forced through the pores by the mechanical predominance of the exterior pressure, and puts an end to the escape. In accurate experiments this may, however, be guarded against by gradually sinking the tube in the water-bath, so as to maintain the water in the interior at the same level as the exterior. When the diffusion-tube is stopped with finely divided or spongy platinum, tightly hammered into a brass collar, the process goes on with the greatest advantage. By experiments with the diffusion-tube Professor Graham determined that each gas has a diffusiveness peculiar to itself, which is greater as its density is less; being inversely proportional to the square root of the density of the gas. Thus the density of the air being 1, its diffusiveness is 1 also. The square roots of the densities of the following gases is here set down, and the power of diffusion as calculated in this manner.

Hydrogen . . . . $\sqrt{0.069}=0.2627$
Oxygen . . . . $\sqrt{1.102}=1.05$
Nitrogen . . . $\sqrt{0.972}=0.986$

and $0.2627 : 1 :: 1 : 3.807 =$ Diffusiveness of Hydrogen.
$0.05 : 1 :: 1 : 0.952 =$ „ of Oxygen.
$0.986 : 1 :: 1 : 1.014 =$ „ of Nitrogen.

The results of experiments coincide so exactly with the law, that the density of a gas may conversely be determined by experiment upon its diffusiveness.

The law of gaseous diffusion, it has been shown, is included under Dalton's hypothesis, that one gas acts as a vacuum with respect to another; for from the physical properties of gaseous bodies it may be deduced that the velocities of gases flowing into a vacuum under like circumstances, are inversely as the square roots of their densities. The velocity of air, of standard density, rushing into a vacuum, has been found to be 1,300 feet in a second of time.

§ 101. It is scarcely possible duly to appreciate in the vast economy of terrestrial adaptations, the importance of this mechanism by which gases and vapours rapidly permeate each other's bulks, and become equally diffused. The atmosphere which surrounds the globe consists, as we shall hereafter show, of a mixture of several aëriform fluids in certain fixed proportions, upon the proper maintenance of which, "by measure and by weight," the welfare of the whole organic creation depends. The processes of respiration and combustion are perpetually tending to the destruction of these nicely-adjusted proportions, by the abstraction of the vital air, and the substitution of another, which is a deadly poison to animal life; and yet, by the simple means which we have described, the poisonous air is not allowed to accumulate, but diffuses itself instantly through surrounding space, while the vital gas rushes, by a counter tendency, to supply the deficiency which the local consumption has created. Hence the invariable uniformity of this mixture, which is one of the most surprising phenomena where all is admirable. The most accurate examination has been made of air which has been taken from localities the most opposed to each other in all the circumstances which can be conceived to affect its purity; by means of a balloon, from a height of 22,000 feet above the level of the sea;—from the surface of the ocean;—from the heart of the most crowded districts of the most populous cities;—from the summit of Mont Blanc;—from within the Polar Circle;—and from the Equator; and no difference has been detected in the proportions of its principal constituents. We shall return to this subject when we touch upon the properties of the different kinds of matter which constitute this wonderful mixture.

§ 102. To complete our view of heterogeneous adhesion, there is one more class of phenomena to which it is necessary to advert, and which is dependent upon the different degrees of intensity in which that force exists between different bodies. Let us take, as a simple illustration, the three substances, rosin, water, and spirits of wine; between the two liquids the attraction is very powerful, and they may be mixed together in any proportions; between the spirit and the rosin, the attraction is also strong, and the solid is readily dissolved in the liquid; between the rosin, however, and the water, there is scarcely any attraction; the former is just capable of having its surface wetted by the latter, but it is wholly insoluble in it. Now if we take a solution of rosin in spirit, and pour water into it, the rosin will resume its solid form, and will be *precipitated*, as it is termed, or fall to the bottom of the vessel in which the experiment is made. The attraction between the spirit and the water is greater than that between the spirit and the rosin, consequently it abandons the latter to unite itself with the former; and this goes by the name of *elective attraction*, as the water is figuratively supposed to exert a choice between the two bodies, to both of which it is capable of attaching itself. If, again, we pour some oil of vitriol into a saturated solution of sulphate of copper, or blue vitriol, we shall have another instance of elective attraction. The water which held the salt in solution will be abstracted by the superior force of the vitriol, and the salt will be precipitated in the solid form.

The same play of attraction is also found in the case of gaseous bodies, and if well burned charcoal be shaken with a solution of sulphuretted hydrogen in water, it will entirely abstract the gas, so that the water will not only be completely inodorous, but the most delicate tests will fail to detect in it the slightest remains of gas.

§ 103. The most usual practical mode of separating bodies which are united by the force of heterogeneous adhesion, is by effecting changes in their physical states by means of changes of temperature. If it be required to recover a solid from its solution in a liquid, the solution is placed in a shallow pan or basin, and heat applied, when the liquid will be *evaporated*, and the solid remain. If it be necessary to preserve the liquid also, as a valuable product, the process is carried on in close vessels, and the vaporized liquid, after quitting the solid, is condensed by refrigeration in a separate vessel. The process is called *distillation*, and may also be applied to mixtures of liquids of different degrees of volatility.

The abstraction of heat, and the consequent decrease of the force of self-repulsion, or the increase of homogeneous cohesion, may also occasionally be employed for the same purpose. Thus, by the application of cold the aqueous part of sea-water may be frozen, and a strong brine will remain behind; or brandy, or any other mixture of water and alcohol, may be frozen so as to leave the spirituous part nearly in a state of purity. Vapours, again, may be separated from gases, by a reduction of temperature; but other forces must be had recourse to for the separation of mixed gases, on account of the inadequacy of all ordinary means to affect their physical state.

CRYSTALLIZATION.

§ 104. WE must yet pause for a short time upon the equilibrium of the two forces of heterogeneous and homogeneous attraction; or rather upon the exact moment when the latter is about slowly to assume the ascendency, and to withdraw a solid from its solution in a liquid under the influence of the former. We have already noticed the similar phenomena which present themselves when the force of homogeneous attraction begins gradually to prevail over homogeneous repulsion: the particles do not solidify into confused masses, but arrange themselves with the utmost order of internal structure and external form.

When the water of a solution of sugar has been partially abstracted, and the concentrated syrup left for some time at rest, this kind of regular solidification takes place; the force of cohesion builds up the solid into the regular well-known forms of *sugar-candy*. If this process of consolidation be hastened, or disturbed, the crystallization takes place in a confused manner, and the texture of the mass is that of *loaf-sugar*.

All those bodies which are denominated salts, and many of which are very commonly known, crystallize in this manner from their solution, and present forms of the utmost symmetry and beauty: thus common salt, under ordinary circumstances, assumes the form of the cube; alum, that of the octohedron; saltpetre, that of a six-sided prism; and epsom salt, that of a four-sided prism. The largeness and regularity of the forms are in general proportionate to the slowness of the operation, and the quantity of solution from which the crystals are deposited. Many crystals are met with in nature which cannot yet be formed by art; such as rock crystal, in beautiful six-sided prisms; the diamond, in the form of the octohedron, &c. &c.; but we cannot doubt, from analogy, that they are produced by the same species of operation as those which we can repeat in our laboratories. The modifications of forces, which were opposed to their cohesion, and gave their particles freedom of action by suspending and counteracting its power, may be, in many cases, unknown to us, but the principle of their operation is plainly to be recognized.

§ 105. The ascendency of cohesion is sometimes determined by apparently slight and almost inappreciable circumstances. Agitation, or a mere vibration, the contact of some foreign substance, or, more certainly, the contact of a crystal of the same substance, will cause the crystallization to commence. It will almost always take place round any solid centre or *nucleus* which may be presented to it, provided such solid be capable of being wetted by the liquid. In the manufacture of sugar-candy, verdegris, sulphate of copper, prussiate of potash, &c., strings, twigs of wood and wires are placed in the solutions, and may generally be found in the centres of very large groupes of these crystals.

If a large glass flask, with a long neck, be filled with a saturated solution of glauber salts (sulphate of soda), and boiled, so as that the steam shall expel all the common air, and the mouth of the flask be accurately closed with a good cork, whilst the vapour is rushing out, it may be cooled down to the common temperature of the air, in a quiet place, without depositing any crystals. Upon the withdrawing the cork the air will rush into the void space formed by the condensation of the steam, and crystallization will almost immediately commence.

This action, as well as that of the solid nucleus, may probably be explained by the assisting action of the heterogeneous attraction of the foreign body for the water of the solution. A portion of the latter attaches itself to the air, which it absorbs, or to the solid, which it wets, and is withdrawn from the solution, the crystallization of which is thus determined.

If a mixed solution of two salts, such as nitre and glauber salts, be made, and divided into two portions, the suspension in one of a crystal of nitre will determine the solidification of that salt alone, whilst only sulphate of soda will be precipitated in the other by a crystal of the latter salt.

The influence of foreign bodies, in modifying the act of crystallization, is also shown in another way: salts which are formed in turbid, muddy solutions, containing earthy or carbonaceous substances, are generally of a larger size, and sometimes of different forms from those which are deposited from pure water. Thus, in the manufacture of tartaric and citric acids, the rough, brown, crystals of the first process are always much larger and bolder than those of the pure transparent products of the last operation, and when some of the animal substance *urea* is added to a solution of common salt, the crystals which are deposited from it are of the octohedral, instead of the cubic form.

§ 106. Crystals may be increased in size, and modified in form, by artificial management, according to a process discovered by M. Le Blanc. This consists in selecting very regular crystals of a salt that have been newly formed, and placing them in a saturated solution of the same salt. A regular solidification of fresh matter will take place upon them, and as the side which is in contact with the containing vessel receives no increase, they must be turned daily to preserve their regularity. After some time the largest and most regular of these crystals is selected, and the same process repeated upon them; and thus crystals larger and more regular than are usually formed in a solution may be obtained.

Dr. Wollaston made a remark upon the spontaneous growth of large crystals at the expense of small ones, in the same solution exposed to changes of temperature, which illustrates in a beautiful manner the alternate ascendency of the two antagonist forces. When the temperature rose the solvent power of the liquid was increased, and some of the solid matter of the crystals was abstracted; but when the temperature again fell this was deposited in a greater proportion upon the larger masses than upon the smaller, so that the latter were in the end entirely taken up, and deposited upon the former.

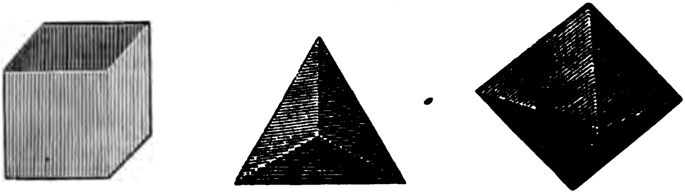
§ 107. Crystallographers early observed, that certain crystalline forms were peculiar to certain classes of substances: thus, each of the different salts which have been already named, has its appropriate form: calcareous spar crystallizes in rhombohedrons; fluor spar, in cubes; quartz, in six-sided prisms, terminated by six-sided pyramids. Crystalline form may therefore serve, to a certain extent, as a ground of distinction between different substances, and is accordingly employed by mineralogists to distinguish one mineral from another. It is also very serviceable to chemists, in assisting them to distinguish different species of the numerous class of salts.

CRYSTALLOGRAPHY, however, from its great extent, now constitutes a separate branch of science; it does not fall within the compass of our present plan to do more than attempt a comprehensive view of the more simple geometrical forms which these solids assume, and the general laws by which they are limited and connected together.

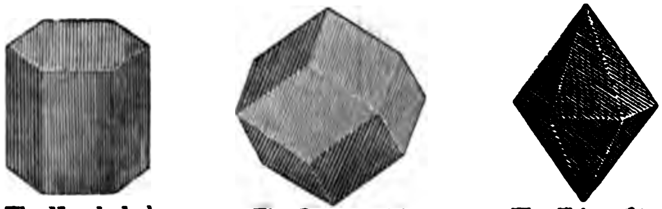
§ 108. The surfaces which bound the figures of crystals are called *planes* or *faces*, and are generally flat. The lines formed by the junction of the two planes are termed *edges;* and the *angle* formed by two such edges, a *plane angle;* a *solid angle* is the point formed by the meeting of, at least, three planes. Their forms are commonly divided into *primitive* and *secondary;* amongst the principal primitive forms are reckoned the *tetrahedron*, the *cube*, the *octohedron*, the *six* and *four-sided prisms*, the *rhombohedron* (24).

§ 109. It is very seldom indeed that these forms are perfect and complete; sometimes extra faces are formed by the *replacement* of an edge, or the *truncation* of an angle. It seems as if the architecture of nature had been interrupted in midway; but it is always obvious

(24) Forms of Crystals.



The Cube. The Tetrahedron. The Octohedron.



The Hexahedral Prism. The Rhomboidal Dodecahedron. The Triangular Dodecahedron.

that if the process had been continued, the perfect form would have resulted. Secondary forms may be conceived to be derived from a primitive intention, so to speak, checked in the original direction, and forced into another. Thus all the eight angles of a cube may be conceived to be truncated, and replaced by eight triangular faces; an extension of which faces would totally obliterate the original faces of the cube, and a secondary *octohedron* would be formed.

§ 110. The science of *crystallography* requires the most exact measurement of the angles and inclination of the planes of crystals; and the instruments by which this is effected are called *goniometers*.

The simplest of these consists of a protractor, or semicircular scale of degrees, and a small pair of compasses or nippers, between which the sides of the crystal are adjusted, and the legs of which, crossing each other at the centre, show upon the scale the number of degrees included between them (25).

But the reflecting goniometer of Dr. Wollaston is at once the most accurate, useful, and elegant of these instruments. A ray of light reflected from the surface of the crystal is employed as the

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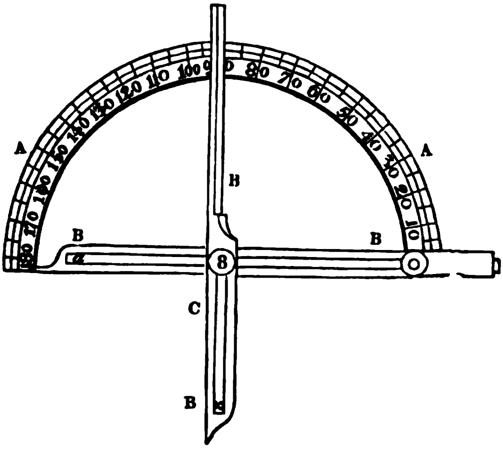
(25) A A is a graduated brass semicircle, and B B B B, a pair of proportional compasses, moving upon the centre and capable of being lengthened or shortened by sliding upon the same centre. The faces of the crystal are embraced by the exterior legs of the compasses, and the value of the angle comprised between them may be read off upon the semicircle by the knife edge of the leg B C B.



radius of the circle, instead of the prolongation of the surface itself. One plane of the crystal is brought into a fixed position with regard to the measuring circle, by means of the ray, and the inclination of an adjoining plane is determined by the arc which it is necessary to turn the crystal to bring the second plane into the position of the first. This method is so accurate that it will give the inclination of planes to each other, whose area is less than $\frac{1}{100,000}$th of an inch, to a minute of a degree (26).

§ 111. But the slow, undisturbed progressive action of the cohesive force not only determines the symmetry of the external figures of crystals, but confers upon them an internal structure which is equally regular, and from which we infer that they are composed

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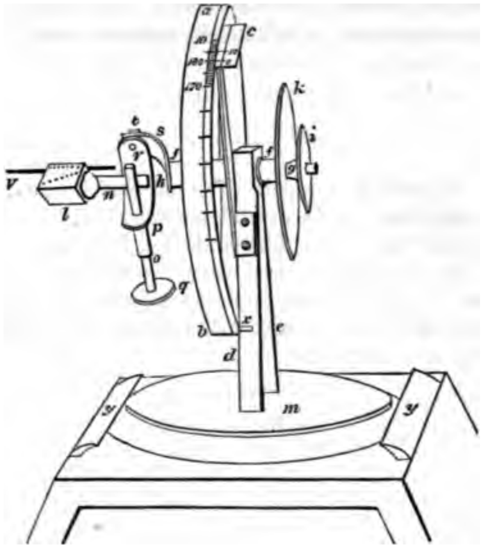
(26) *a b* is the principal circle, graduated on the edge to half degrees; *c* is a brass plate, graduated as a vernier, and fixed upon the pillar *d*; *f f* is the axle of the circle, and passes through the upper part of the two pillars *d e*; *g h* is an axle inclosed within *f f*, and turned by means of the small circle *i*, which communicates a motion to all the apparatus on the left of *h*, without moving the principal circle. The latter is turned by moving *k*; and as the axle of the principal circle includes the former, we necessarily move the whole instrument by moving the circle *k*. The crystal to be measured is fixed by wax to the end of a plate of brass, *n*,



placed in the upper part of the brass stem *o*, by the movements of which, combined with the motion of the interior axis, it may be accurately adjusted by comparison with some fixed horizontal line, to which its prinof imperceptible molecules of certain geometrical dimensions, no less definite than the sensible solids whose properties they determine. This is not immediately apparent to the eye, but is indicated by the action of any force carefully applied, and just sufficient to destroy their texture. Mechanical force even is sufficient to indicate the regularity and difference of arrangement in different species. It was long known to diamond-cutters that that precious gem might be split in certain directions with greater facility than in others, but M. Haüy was the first to employ *cleavage* in the regular dissection of crystals.

§ 112. He took a six-sided prism of calcareous spar, and in attempting to split it by the edge of a knife, gently struck on the back with a small hammer, he found that of the six edges of the superior base the three alternate only yielded to the blow, and that the division there took place at a certain determinate angle. The three intermediate edges resisted this division; but in applying the same force to the inferior base of the crystal the intermediate edges alone yielded. By following up this cleavage, in the natural directions thus pointed out, the new formed faces met together, and he at length obtained an *obtuse rhombohedron* of definite angles, which was further divisible, in the direction of it's planes, into an infinite number of similar smaller *rhombohedrons*. He also found that any crystal of calcareous spar, of whatever exterior form (and its varieties amount to several hundred), could, by careful cleavage, be resolved into similar solids, and into no other regular geometrical

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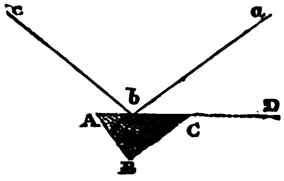
cipal edges are to be made parallel. The reflected image of the bar of a window, from the faces of the crystal, compared with another bar, will answer the purpose very well. The circle must be adjusted to 0° when the crystal is in this position, and then by turning it round till the reflection of the same bar is seen from an adjoining face, the number of degrees, &c., read off by the vernier will measure the complement of the angle which they make together.



In a section of the crystal, let A C B be the angle formed by two of its planes, let *a b* be the ray of light, which after reflection will enter the eye at *c*. If the crystal be now turned round, till the side C B come into the position of C A, it is obvious that the crystal must have gone through an angle equal to D C B, which is the supplement of A C B, the angle formed by the planes of the crystal.

shape; the form persisting to the utmost limit to which regular mechanical division can be carried (27).

§ 113. Other substances are capable of similar dissection; but the ultimate form is, in many cases, peculiar to the substance so examined. A crystal of *galena*, (sulphuret of lead) whether of a cubic or octohedral shape, can readily be separated by mechanical force into a number of small cubic particles.

If we take a cube of *fluor-spar*, and apply the edge of a knife with a little dexterity, we shall find that its eight solid corners may be removed, and that the new formed planes will coincide with those of a regular octohedron. We may go on separating slices from any of these faces, all of which may be split into *acute rhombohedrons*. These rhombohedrons, unlike the *obtuse rhombohedrons* of calcareous spar, will be found to be not only divisible in directions parallel to their six faces, but may be divided into two tetrahedrons and one octohedron. The four solid angles, again, of the two tetrahedrons may be split off, and two octohedrons will remain; and the octohedrons again may be divided into six smaller octohedrons and eight tetrahedrons. Thus the whole mass may be resolved into tetrahedra and octohedra, no one of which can we conceive so small as not to be again divisible in a similar manner (28).

§ 114. Such a regular cleavage, or yielding of the force of cohesion in particular planes, must obviously depend upon regularity of internal structure, which may also be made to appear by a gentle application of other than mechanical forces.

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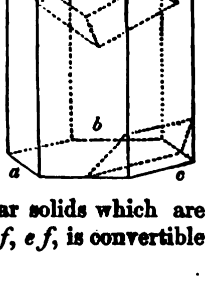
(27) *a b c*—*a b c* represents a six-sided prism of calcareous spar; at *b* and *c* above, and *c* below, are shown three of the new faces produced by the cleavage, which are inclined at an angle of 45°. The obtuse rhombohedron is seen in its relative situation to the including prism.



(28) The following figures represent the regular solids which are derivable from the cleavage of fluor-spar. The cube, *e f*, *e f*, is convertible

If we take a mass of alum of sufficient size, all traces of whose exterior crystalline form have been removed by cutting and grinding, and expose it to the solvent power of water, the fluid will act upon it at first in all directions alike; but as the water approaches its point of saturation the force of heterogeneous adhesion diminishes, and is nearly balanced by the force of homogeneous cohesion, which latter only yields ultimately in those directions of least resistance, which are determined by the regular structure of crystalline arrangement. Under these circumstances its surface will become embossed with the forms of octohedrons and sections of octohedrons, and an immense variety of geometrical figures stamped, as it were, or carved upon its substance (29). Other salts will present analogous phenomena, and metals themselves, which have been slowly cooled from a state of fusion, exhibit a similar regular arrangement of their particles when subjected to dissection by the force of chemical affinity in the action of acids. A mass of nickel thus soon becomes covered with tetrahedral figures of great relief and beauty, by the action of nitric acid; and gold itself, carefully cast and cooled, by the action of *aqua regia*. The beautiful forms of the *Moirée metallique*, which at one time excited so much attention and admiration in their application to ornamental purposes, were produced by the action of weak acids to common tin plate, and the very cheapness arising from the simplicity of the operation soon brought the manufacture into disrepute.

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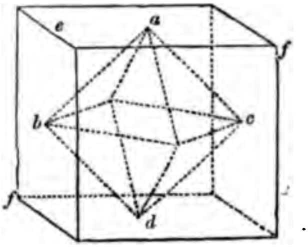
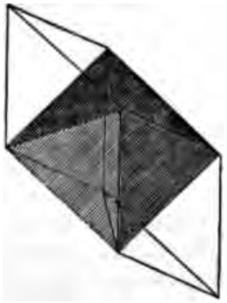
into the octohedron, *a b c d*, by division in the direction of its solid angles. The acute rhombohedron may also be extracted from a similar cube, by





making two successive and parallel sections in the same directions, and by the removal of the tetrahedron from each extremity the octohedron may be easily obtained.

(29) The following figures represent the dissected forms of a mass of alum in water. The first appear upon the faces which are inclined to

§ 115. HEAT may also be employed as the antagonist force to develope the beautiful architecture of homogeneous attraction. If a large crystal of antimony be introduced into a portion of fused sulphuret, and the heat be moderately continued, it will begin to melt down; but so far from this taking place uniformly at the surface, crystals will sometimes be left projecting half an inch from it; and in other places the cavities left by fused crystals will be so large, and have such perfect surfaces, that their angles may readily be ascertained. In order to observe these phenomena it is only necessary to remove the half-fused piece of sulphuret from its hot-bath, and allow it to cool.

§ 116. Definite structure in certain solids, which cannot exactly be called crystalline, because they do not present exact geometrical figures, may be rendered apparent by a similar opposition of forces. Pure *malleable* bar-iron, by the action of dilute muriatic acid, may thus be shown to be constituted of bundles of fibres running in a parallel and unbroken course throughout its length; while different varieties of cast iron will present congeries of plates, and a structure more nearly approaching the crystalline. The peculiar toughness of the one, and the fragility of the other, derive their explanation from this difference of texture.

§ 117. The regular direction and antagonism of such forces is again displayed in a very interesting manner, by the action of quicksilver upon small bars of tin. The force of adhesion between

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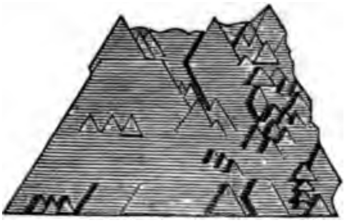
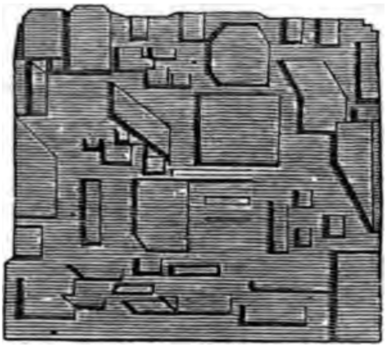
each other at the same angles as those of the faces of the octohedron: the second, upon planes which would be tangents to the edges of the same figure, or upon the sides of a four-sided prism, of which the two pyramids of the octohedron would be the summits.





these metals is very strong, and is capable of entirely overcoming the force of cohesion. If a small square bar of tin be laid horizontally, be just covered with mercury, and, to preserve uniformity of action, be frequently turned upon its different faces, at the expiration of twenty-four hours minute fissures will begin to appear along its lateral and terminal edges. As the process continues the cracks will widen, and about the third day they will open to such a degree as to show that the bar is resolved into four equal, trihedral, rectangular prisms, with two equal angles. These may readily be separated from each other by the point of a knife, as well as two similar pyramids from the two extremities, with angles at their basis of 45°. It is indifferent to this result whether the square form be given to the bar, by casting, hammering, or the filing down of any other shape.

Here it would appear, that as the mercury penetrates the four faces of the bar, the original force of cohesion is weakened, a new force of cohesion between the particles of the amalgam draws them towards the centre of the four rectangular prisms into which we may conceive the bar to be divided, and causes the mass to separate along the lines of least resistance, which coincide with the edges (30).

§ 118. A similar effect may be produced by careful hammering upon bars of malleable metals. If square bars be hammered upon the edges, and the blows repeated round them, so as to give them a cylindrical shape, they soon become what is technically called rotten, and break into fibres; but when the blows are directed parallel to their faces, they are capable of great extension; but many of them, by alternate hammering upon each face, ultimately split along the edges in a manner very similar to that which is produced by the heterogeneous adhesion of the mercury

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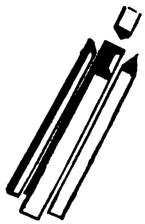
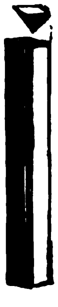
(30) Dissected bars.



This figure shows the four trihedral bars which result from the disintegration of a square bar of tin by the action of mercury.



In this figure is represented the regular crack which occurs in the edge of the bar previously to its final separation, together with the small pyramid detached from the summit.

to the bar of tin. When it is desired to give a round form to any part of a square bar, it is effected by confining it in a kind of form or mould, and the mechanical force thus applied produces an equality of pressure. It is by a similar precaution to equalize the pressure, that metals are capable of being drawn into fine wires, through circular holes in steel plates.

§ 119. The phenomena of crystalline structure which have now been described, have given rise to two rival hypotheses, with regard to their cause, and to account for the forms of the molecules which are thus capable of being built up into the beautiful geometrical solids which have in all times excited the admiration of the curious.

Guided by the mechanical dissection of different crystals, of which we have already given an account, M. Haüy imagined that the form which was ultimately obtained by following up the cleavage till the new formed planes met together in a symmetrical manner, and which in the case of calcareous spar is a rhombohedron of definite angles (27), constituted the primitive form of the substance, and was the form, in fact, of its ultimate molecules. From aggregations of these, externally modified according to geometrical laws, he conceived all *secondary* forms of the same substance might be produced. There is no difficulty, in fact, in admitting that inconceivably small *parallelopipedons* of all varieties of angles, may be built up into masses which would have the same relations of sides and angles. He further supposed that the external modifications of this structure, which produce the numberless varieties of secondary forms, but which are still limited by certain definite geometrical relations to the primitive form, originate from *decrements*, or deficiencies of particles, taking place in the act of crystallization, on different edges and angles of the primitive form. Thus, if upon a compound cube made up of a large number of small cubes, we place layers of cubic particles, decreasing each by a row of particles parallel to the edges, till a pyramid is constructed upon each, terminating in a single particle, the figure will become converted into a dodecahedron, with twelve equal rhombic faces (31). If the *decrement* were to take place upon the angles, instead of the edges of the original cube, the figure would be converted into an octohedron. By decrements of more than one row of particles, and by intermediate and mixed decrements taking place, according to the laws of symmetry, it may be shown that an almost infinite variety of secondary forms may be constructed, all of which would be related by geometrical laws to the primitive form, and all of which might be assumed by the substance to which it belongs. No objection arises to this hypothesis, from the non-appearance of the original form in these secondary structures, for by multiplying the number of particles, and diminishing their size continually, we soon arrive at a limit where the primitive solid becomes insignificant, and, in fact, is actually lost in the comparison.

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(31) The structure of the rhombic dodecahedron from cubic

§ 120. But we have already seen that the mechanical dissection of some substances affords more than one ultimate form, as in the case of fluor-spar. Both the octohedron and the tetrahedron result from the cleavage of this remarkable substance; which, then, is to be taken as its primitive form,—the form of its integrant particles? Neither of them, by their aggregation, can fill space like *parallelopipedons*. They may be both *symmetrically* arranged, so as to afford to the eye the external forms of the secondary crystals, which may be geometrically calculated from their various decrements; but the tetrahedral arrangements would be regularly interspersed with octohedral vacuities; and the octohedral with tetrahedral cavities. Such structures, moreover, would be unstable, and contrary to all the established laws of attraction in matter (32).

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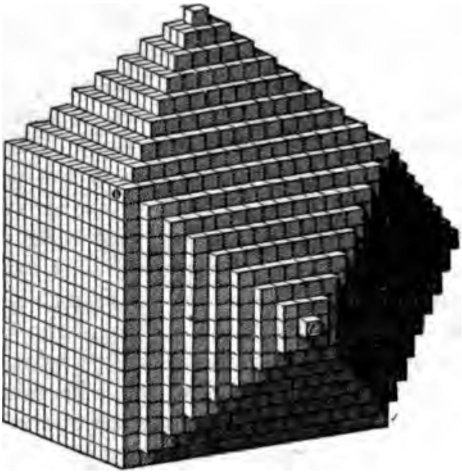
particles is shown in this figure.—



(32) The following figures present the construction of the tetrahedron and octohedron, each with tetrahedral and octohedral particles. It will be

The phenomena of dissection would be quite opposed to the hypothesis that solids thus attract one another by their edges, and not by their sides: for a cube so put together of octohedral particles would necessarily split in directions parallel to the faces of the cube, and not to those of the octohedron. The fact is, that M. Haüy himself was not unaware of the difficulties of his system, regarded as a *physical explanation* of the phenomena of crystallization; but, without insisting upon this view of the subject, as some of his disciples have injudiciously done, he made use of it in a legitimate way, to present together in a general point of view a great number of particular facts; and it enabled him to reason from the known

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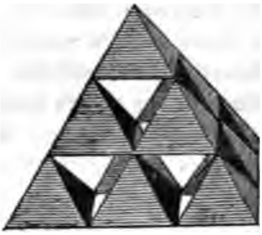
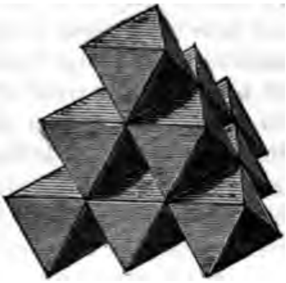
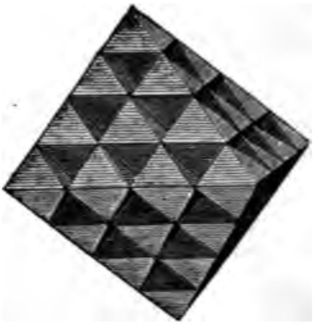
seen that the tetrahedral structure is interspersed with octohedral vacuities, and the octohedral with tetrahedral spaces; so that one might be conceived to be taken out of the other.



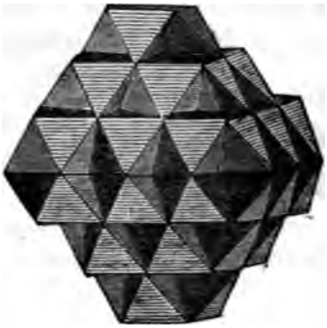
Tetrahedral Tetrahedron.



Octohedral Tetrahedron.



Octohedral Octohedron.



Tetrahedral Octohedron.

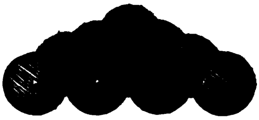
All bodies may be considered as attracting each other, as if the whole of their matter were condensed into their centres of gravity, which therefore would in all cases be drawn as closely as possible together: under this law solid tetrahedra and octohedra would apply themselves to each other by their sides, and not by their edges.

to the unknown in a truly philosophic manner. Like "a geometrical diagram, it had its important uses in the advancement of science, but it had no physical meaning*.

Dr. Wollaston proposed by another ingenious hypothesis, which had been already developed to a considerable extent by Dr. Hook, to obviate the necessity of admitting the interstitial vacuities in those arrangements which the tetrahedral and octohedral particles afford. He suggested that the elementary particles of this class of substances might be considered to be perfect spheres, and to assume that arrangement which would bring them as near to each other as possible.

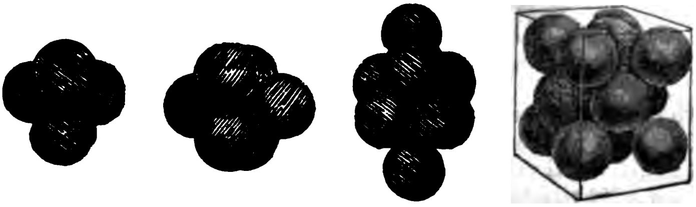
The relative position of any number of equal balls in the same plane, when gently pressed together, every three forming an equilateral triangle, is familiar to every one; and it will be evident, from inspection of a number of small shot placed together on a plate, that if they were cemented together, and the stratum thus formed were afterwards broken, the lines in which they would be disposed to break would form angles of 60° with each other (33).

If a single ball were placed at rest upon such a stratum, it would be in contact with three of the lower balls; and the lines joining the centres of four balls, so in contact, or the planes touching their surfaces, would include a regular tetrahedron, having all its sides equilateral triangles. The construction of the acute rhombohedron, octohedron, and cube, on the same principle, is as simple as that of the octohedron; and any or all of these solids might be extracted from a sufficient number of such spheres, regularly piled up in the order which is adopted for shot in arsenals, without disturbing their original arrangement (34).



(33) The arrangement of balls pressed together in the same plane.

(34) These figures represent the structure of the tetrahedron, octohedron, acute, rhombohedron, and cube, with spherical particles.



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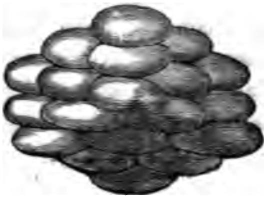
* Whewell's *History*.

§ 121. Dr. Wollaston also showed that, by substituting for these molecules forms nearly allied to the sphere, such as oblate and oblong spheroids, many forms might be constructed which would not result from perfect spheres, but which are well known to crystallographers. Thus by grouping together oblate spheroids, the proportion of whose axes are as 1 to 2.87, in the same manner as the spheres in the formation of the acute rhombohedron, an oblate rhombohedron would result, whose angles would be those of calcareous spar. All solids thus composed would obviously be split by mechanical force, in directions parallel to their faces.

If the elementary spheroids, on the contrary, were oblong, instead of oblate, their centres would approach nearest to each other, by mutual attraction, when their axes were parallel, and their shortest diameters in the same plane. The manifest consequence of such a structure would be, that a solid so formed would be liable to split into plates at right angles to its axis, and the plates would divide into prisms of three, or six sides, with equal angles; a structure and a cleavage, which are common to many well-known minerals, as the *beril*, *phosphate of lime*, &c. (35).

§ 122. Amongst the physical phenomena which are calculated to lead to a knowledge of the intimate structure of crystallized bodies, we must not forget to mention the discovery of Mitscherlich, of the unequal expansion and contraction of certain classes of crystals by changes of temperature. Crystals belonging to the regular system, which we have imagined to be composed of perfectly spherical particles, expand equally in every direction by heating. Other crystals expand more in one direction than another, and show a tendency to approach to the nearest form of the regular system. Thus the angles in calcareous spar vary 8¼′ between the temperatures of melting ice and boiling water, the obtuse angles diminishing, and the form approximating to the cube. The experiments by


(35) A rhombohedron, formed of oblate spheroidical particles.

A six-sided prism, formed of oblong spheroidical particles.

which Professor Mitscherlich established this important point is one of considerable delicacy; but common observation will be sufficient to prove it in several obvious instances. Melted *litharge*, allowed slowly to solidify and cool, when it reaches a particular point flies into minute fragments, from the irregularity of its contraction; and the double *sulphate of potash and copper* exhibits the same phenomenon in a very marked manner. If a little of this salt be melted in a spoon over a spirit-lamp, and the heat withdrawn, it congeals into a solid, of a brilliant green colour, and remains solid and coherent till the temperature sinks to nearly that of boiling-water, when all at once its cohesion is destroyed, and the whole is resolved into a heap of incoherent powder.

§ 123. As far as it has been examined, the hypothesis of the spherical and spheroidal molecules of crystals has not been found inconsistent with any of the established laws of the action of FORCE; either as regards the attraction which is conceived to group the particles together, or the antagonist forces by which they may be modified, cloven, or dissected; but, for the present, crystallographers and mineralogists seem to have agreed to drop all speculations with regard to the internal structure and ultimate forms of the molecules of crystals, and confine themselves to the experimental determination, and the geometrical relations of their exterior forms.

§ 124. These geometrical properties are referable chiefly to what are termed the *axes of symmetry* of a crystal; that is, those lines in reference to which every face is accompanied by other faces, having the same positions and properties. Thus, a rhombohedron of calcareous spar may be placed with one of its obtuse corners uppermost, so that all the three faces which meet there are equally inclined to the vertical line. In this position every *derivative* face which is obtained by any modification of the faces or edges of the rhombohedron, implies either three or six such derivative faces; for no one of the three upper faces of the rhombohedron has any character or property different from the other two; and therefore there is no reason for the existence of a derivative from one of the primitive faces, which does not equally hold for the others. Hence the derivative forms will, in all cases, contain none but faces connected by this kind of correspondence; the axis thus made vertical will be an axis of symmetry, and the crystal will consist of three divisions ranged round this axis, and exactly resembling each other.

§ 125. But this is only one of the kinds of symmetry which crystalline forms may assume. Instead of being *uniaxal*, they may have three axes of complete and equal symmetry at right angles to each other, as the cube, and the regular octohedron;—or two axes of equal symmetry, perpendicular to each other; and to a third axis, which is not affected with the same symmetry with which they are; such a figure is a square pyramid;—or they may have three rectangular axes, all of unequal symmetry, the modifications referring to each axis separately from the other two. In the nomenclature of Mohs, which is now most commonly adopted, these systems are respectively distinguished as the *rhombohedral*, the *tessular*, the *pyramidal*, and the *prismatic*.

The introduction of this systematic arrangement of crystalline forms according to their degree of symmetry, is due to the concurrent labours of Weiss and Mohs. It is founded rather upon mathematical relations than experimental facts; but it has been remarkably confirmed by some striking physical properties of minerals, particularly with regard to their action upon light, some of which we shall hereafter have occasion to examine.

§ 126. There is, however, one curious phenomenon in the crystallization of certain substances, which has not been explained by any of the hypotheses which have yet been framed, and which awaits some higher stage of inductive generalization than that at which we are at present arrived; and that is, they are capable of assuming two forms, which belong to different systems of crystallization, and cannot be derived the one from the other: these have been called *dimorphous* bodies, and they occur both amongst simple and compound substances. *Sulphur* deposited from solution in *bi-sulphuret of carbon* crystallizes in *octohedrons*, with *rhombic bases*, and also occurs in this form in native specimens; but when it is melted, and allowed to cool slowly, till part of the mass is consolidated, and when the remaining liquid is poured off, crystals are obtained in the form of an *oblique rhombic prism*. These two forms have incompatible geometrical relations to each other. Pure carbon occurs also in nature in two states; as *diamond*, which crystallizes in regular octohedrons; and as *graphite*, which crystallizes in six-sided plates, which are also incompatible forms. Amongst compound bodies calcareous spar, as we have seen, crystallizes with the *rhombohedral* structure, and also as *arragonite*, in forms which have reference to a *rectangular octohedron;* and *iron pyrites* is also met with in the common form of the cube, and with an incompatible prismatic structure.

§ 127. There are some solids, again, which are capable of slowly changing their internal structure, or of even rapidly passing from one state to another, when the unstable equilibrium of their particles is disturbed by slight mechanical force.

Sugar which has been rapidly boiled down to a solid consistence, in the well-known form of *barley-sugar*, is perfectly transparent, is difficultly broken, and presents a glassy fracture. After a little time it becomes opaque, and almost friable. In the same way brass-wire will in the lapse of time become brittle, and unfit for mechanical purposes. If crystals of *sulphate of nickel*, or *seleniate of zinc*, in the form of prisms, be laid on paper, and exposed to the rays of the sun, in a few moments they will become opaque, and will be found when broken to be made up of minute octohedrons, with square bases. Similar crystals of *sulphate of zinc* undergo a like change, but more slowly. Fresh sublimed *iodide of mercury* also affords a beautiful example of this readjustment of the cohesive force. A slight scratch with a hard substance, as the point of a pin, is sufficient to set the particles of the crystals in motion, and changes their colour from a sulphur-yellow to a bright red.

HEAT.

§ 128. WE have already traced the origin of homogeneous repulsion, the antagonist force to homogeneous attraction, or cohesion, to that cause, whatever it may be, which produces in us the sensation of heat: it is necessary that we should now inquire with more precision into the nature of this subtle agent, and the laws which regulate its action.

And first, with regard to the active sources of its abundant supply: the principal of these is the sun. The most inattentive observer cannot have failed to remark that the direct rays of the sun,—some communication that is from that splendid but distant globe, which we designate by rays,—impress him with the sensation of heat; and without this benign influence upon the animate and inanimate creation, all nature would be bound in the adamantine chains of cohesion: and could we imagine man to exist for a moment upon the face of the globe under its privation, vain would be all his puny efforts to remedy the defect from artificial sources of this life-preserving agent. The conflagration of every combustible upon the face of the earth would be insufficient to compensate for twenty-four hours the absence of the glorious orb of day.

§ 129. The second source to which we may advert, we may distinguish as mechanical, and consists in the friction, or rubbing together of solid substances. In this operation strong mechanical force is opposed to the forces of cohesion, or adhesion and heat is generated by the reaction of the two.

From some late experiment of M. Becquerel, it appears that when a rough body is rubbed against another with a smooth surface, the former becomes hotter than the latter. When polished glass is rubbed against cork the first becomes the hotter in the proportion of 34 to 5: ground glass becomes hotter than cork in the proportion of 40 to 7. Silver and cork—the first becomes hotter than the second, in the proportion of 50 to 12. No change in the state or qualities of bodies, thus acting upon each other, necessarily accompanies the evolution of heat; neither is it necessary that they should be of different natures, or possessed of any opposition of qualities. Many familiar instances of high degrees of heat, derived from this source, will readily occur to a reflecting mind.

Two pieces of wood, rubbed together, speedily become hot; and when the force and the velocity are great so much heat may be evolved as to occasion combustion. The axles of the wheels of machinery, or of carriages, not unfrequently take fire from this cause; and it is well known that certain tribes of Indians, with a dexterity and address which we do not possess, have so far applied observation to practical purposes, that they are in the habit of kindling their fires by this means.

The sparks of the common flint and steel consist of small particles of the metal struck off by the stone, and burning under the influence of the heat elicited by the blow; and every one has had an opportunity of observing the more copious display of fire from the same source at the knife-grinder's wheel.

In North America, where the mechanical force of falling water is abundant, the surplus power of certain mills has been most ingeniously turned to good account, by causing large plates of iron to rub against each other, and applying the heat thus evolved to the warming of the building. The most remarkable circumstance attending this source of heat is, that it is absolutely unlimited: so long as solid bodies can be made thus to act mechanically upon each other, heat is given out.

Count Rumford endeavoured to ascertain how much heat was actually generated by friction. When a blunt steel borer, three inches and a half in diameter, was driven against the bottom of a brass cannon, seven inches and a half in diameter, with a pressure which was equal to the weight of 10,000lbs., and made to revolve thirty-two times in a minute, in forty-one minutes 837 grains of dust were produced; and the heat generated was sufficient to raise

113lbs. of the metal 70° of Fah.,—a quantity of heat which is capable of melting six pounds and a half of ice, or of raising five pounds of water from the freezing to the boiling point. When the experiment was repeated under water, two gallons and a half of water, at 60°, were made to boil in two hours and a half.

§ 130. The third source is chemical, or the action of particles of dissimilar or heterogeneous substances upon each other, accompanied by complete change of properties. All cases of common combustion, all our artificial processes for obtaining light and heat, are familiar examples of this action. The changes which take place in the active bodies during this evolution of heat, it will be a principal part of our business to inquire into hereafter: we have only at present to remark, that the heat evolved in each case, however copious and intense, is limited and proportionate to the quantities of the reacting substances.

§ 131. The fourth source of heat, but probably nearly allied to the last, is electrical. That force which we have recognised as arising from the friction of glass or resins, by operating, upon larger surfaces, may be accumulated in the form of a spark, which will ignite combustible substances. This action we must also refer to future investigation.

§ 132. A fifth source is physiological, and exists in ourselves. Heat is a product of animal life: we are conscious of this in ourselves—we can feel it, and we can judge of it by our sensations, when communicated from other persons and other animals: we can increase it in ourselves by muscular exertion; our hands and our faces burn, and in this state we can communicate the sensation of heat to others.

Heat and cold, in fact, when referred to our sensations, are but comparative terms, and depend upon the temperature of our bodies at the time of experience. If we raise the temperature of one hand by plunging it in hot water, and at the same time cool the other in cold water, upon removing both into a basin of tepid water, the same water will feel warm to one hand and cold to the other. Any estimation, therefore, of temperature by sensation must necessarily be extremely vague.

§ 133. Now, in none of these various actions of material bodies, which we have thus recognised as sources of heat, is there any loss of material substance. Notwithstanding the copious evolution of this wonderful agent, the quantity of the active matter—its weight—remains the same, whether combination ensue or not.

This something, then, which is generated in ourselves, or which may be communicated to us from any of the sources which have just been named,—which we recognize by our sensations, and denominate heat, may be communicated also to every form of matter without increase of weight; and these can again impart it to us without loss of ponderable matter.

Thus a piece of iron placed in the direct rays of the sun, will soon feel warm to our hands; or when made red hot in the fire, will communicate heat to us even at a distance; but its quantity of ponderable matter will be neither increased nor diminished.

The accession of heat, and consequent increase of repulsive force amongst the homogeneous particles of matter, not only determines the changes of state from solid to liquid, and from liquid to aëriform, which we have already noticed (§ 63), but produces expansion of bulk in bodies in all these states; and we must now inquire into the laws of this expansion, and the steps of the progress of a body from one physical state to another.

§ 134. The increase of bulk, for the same increase of heat, differs very much in the different classes of substances. In solids it is small; in liquids greater; and in aëriform bodies the greatest of all. It also differs in bodies of the same class. By accurate measurement it has been ascertained that in raising the temperature of the following solids from the freezing to the boiling-point of water,

Lead expands in volume . .	$\frac{1}{350}$th
Iron ,, ,, ...	$\frac{1}{800}$th
Glass ,, ,, ...	$\frac{1}{1000}$th

that is to say, 350 cubic inches of	Lead	become .	351
800 ,,	Iron	,, .	801
1000 ,,	Glass	,, .	1001

by this accession of heat.

The subjoined table includes the most interesting results of the best experiments upon the subject.

Table VII. *Linear Dilatation from the Freezing to the Boiling-point of Water.*

1000000 of	Glass tube	become	1000861
„	Crown glass	„	1000875
„	Platinum	„	1000856
„	Cast iron	„	1001111
„	Steel	„	1001189
„	Gold	„	1001460
„	Copper	„	1001712
„	Brass	„	1001783
„	Silver	„	1001890
„	Tin	„	1001937
„	Lead	„	1002867

The expansion in volume may be obtained, without sensible error, by trebling the number which expresses its increase in length, where, as in the above instances, the fraction of its length is small.

By the same change of temperature the following liquids augment their volumes in the annexed proportions:—

1000	parts	of water	become 1046
1000	„	of oil	1080
1000	„	of quicksilver	1018
1000	„	of spirits of wine	1110

But every aëriform substance, provided it be not in contact with a liquid, expands in the same proportion; one thousand parts of air becoming 1373, by being heated from the freezing to the boiling-point of water.

These expansions take place gradually, and when the heat is withdrawn the bodies return to their original bulks, by corresponding regular contractions.

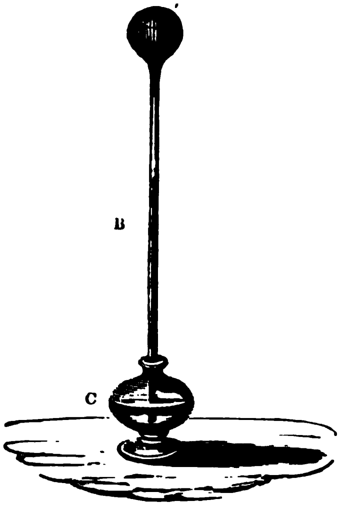
§ 135. Now the perfection of science depends upon accurate measurement and instrumental precision: there can be no advance of a single step without these essential means. The unassisted senses are by no means sufficient to determine quantities with anything approaching to the necessary degree of exactness. The hand, or the application of muscular force, may indeed inform us that one body differs very greatly from another in gravity; but without the balance to determine weights which would be wholly inappreciable in this way, the science of chemistry could not have existed. So, our sensations may inform us that one body is hotter or colder than another; but without some means of measuring differences of temperature, which would wholly fail to affect our senses, our knowledge of heat would have been small indeed.

It is by observing that expansion or enlargement of volume is always produced by the same causes which affect us with the sensation of heat, that we come to regard expansion as the indication of heat; and as this is an effect which can be ascertained with the utmost precision, we adopt its measure as that of the cause which produces it.

If a certain quantity of air, or of a liquid, or solid, undergo an augmentation of volume which we can determine when exposed to a certain source of heat, and when we expose it to another source of heat that expansion is doubled, there is reason to infer that the intensity of the second source is double that of the first. And this is the principle of that useful instrument the thermometer.

§ 136. The honour of the first invention is generally ascribed to Sanctorio, an Italian physician, about the year 1590; but the same contrivance probably suggested itself in an independent manner to Cornelius Drebel, about the year 1610. One thing, however, is certain, viz., that it dates from about the beginning of the seventeenth century.

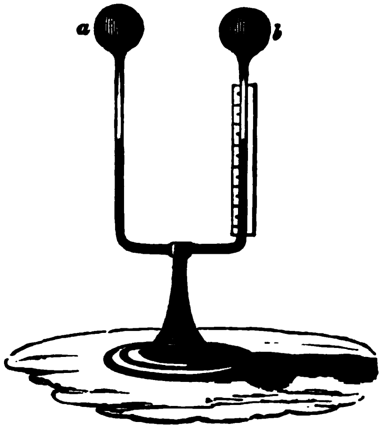
The thermometer of Sanctorio consisted of a hollow glass globe, attached to a long stem, open at the opposite extremity; a portion of air was expelled from it by the expansive force of heat, and the end of the tube was then immersed in a coloured liquid (36). As the



(36) Air thermometer of Sanctorio. B is the stem of the instrument, the upper end of which terminates in a capacious ball, while the lower dips below the surface of the liquid in the vessel C. When a portion of air has been expelled from the ball by heat, and it is afterwards cooled, the superior elasticity of the outward air raises a column of liquid in the stem.

included air cooled, and returned to its former volume, the liquid rose in the tube, from the superior elasticity of the external air pressing upon the external surface of the liquid. A scale of equal parts was applied to the stem, by which the expansion of the included air, from heat, or its contraction from cold, could be measured, by the movement of the column of liquid. It was liable, however, to the objection of being acted upon, not only by the expansion of the included air, but by the barometric changes of the exterior atmosphere.

§ 137. Air has not only the advantage of being extremely regular in its expansion, but also of indicating very minute changes of temperature, by the great alterations of volume which it undergoes from being heated and cooled; and a modification of the air-thermometer is now very often used in delicate researches. It was invented in the year 1676, but was chiefly brought into notice by the admirable experiments of the late Sir John Leslie. It consists of two thin equal glass balls, united together by a tube bent twice at right angles, the balls being situated at the top of the perpendicular arms, and cut off from any communication with the atmosphere. Both balls contain air, but the greater part of the tube is filled with a coloured liquid (37). This instrument cannot be affected by any change of temperature, acting alike upon both the balls, for the pressure on the opposite surfaces of the included liquid will in such cases be always equal; but it will instantly indicate the slightest difference of temperature between the two balls; for the elasticity of the air on one side being greater than on the other, the liquid will be forced towards the side where the



(37) Differential Thermometer of Leslie. The liquid in the two stems is shown at the same level as when both balls are exposed to the same temperature: any difference can be accurately measured upon the attached scale.

temperature is the lowest, and the difference may be measured upon a scale. The instrument has hence been named the *differential thermometer.*

§ 138. The first great improvement in the thermometer for ordinary purposes was made by the members of the Italian Academy del Cimento, in 1660, who substituted the expansions of a liquid as the measure of heat; inclosing it in a glass ball and tube, which was afterwards cut off from all communication with the variable atmosphere, by softening the extremity of the glass at the flame of a lamp, and hermetically sealing it: the instrument thus at once became more accurate, and more manageable. Spirits of wine was the liquid first employed, and quicksilver was afterwards used by Halley and Sir Isaac Newton: both liquids are now at times employed for different purposes.

§ 139. Still the thermometer wanted much of perfection; for different instruments thus constructed could not afford comparable results, although experiments made with the same instrument were comparable with one another. For the last great improvement we are indebted to Newton. It had been observed by another eminent philosopher, Hook, that the temperature of melting ice was always fixed and permanent; and that the temperature of boiling water was equally invariable, provided the pressure of the atmosphere did not change. The sagacity of Newton pointed out the application of these observations to the completion of the instrument. If we immerse the mercurial thermometer in melting snow or ice, the liquid will gradually contract, and sink in the stem to a certain point, and then stop; and however long we may allow it to remain in the ice it will sink no lower. The experiment repeated at any time, or in any place, will afford the same results; the liquid will always sink to the same part, and no further. By marking this we obtain one fixed point, which must be the same in every thermometer which is subjected to the trial. If we now remove the instrument into a vessel where it may be surrounded with boiling water while the barometer indicates an unvarying pressure of thirty inches, the liquid in the glass will expand till the mercurial column reaches a certain height, where it will again become perfectly stationary, and afford another invariable point of comparison. The distance between these two points measures the amount of expansion of the whole quantity of the included liquid: or rather is the measure of the difference of the expansion of the liquid and the glass; for both expand. Upon the supposition that the expansion of the two is equable, and that the bore of the glass tube, in which the liquid moves, is equal throughout, the distance between the two points may be divided into any number of equal parts, and the equal amounts of expansion or contraction measured by them may be taken to indicate equal increments or decrements of temperature, which will correspond in all instruments similarly graduated. Upon the supposition, moreover, that the law of expansion continues the same both above the boiling and below the freezing-point of water, an extension of the same scale of equal parts will afford the means of measuring greater and less degrees of temperature, with reference to the same fixed standard.

§ 140. It is much to be lamented that the philosophers of different nations have not agreed upon the arbitrary division of this invariable quantity; and, consequently, we have various thermometric scales which perpetually require to be reduced from one to the other in the different necessary comparisons. In this country it is divided into 180 parts or degrees; but the freezing-point is not designated by Zero, or 0°, but by the number 32°, making the boiling-point of water 212°, instead of 180°. This scale was introduced by Fahrenheit, a German artist, who conceived that he had obtained the lowest possible degree of cold, by the mutual action of common salt and snow. If a thermometer be introduced into such a mixture it will contract to about $32\frac{1}{180}$th parts of the expansion between freezing and boiling water, and thus the commencement of this scale, or 0, was placed at this point.

In France the thermometer named Réaumur's was for a long time generally employed: the interval between freezing and boiling water in this instrument is divided into eighty degrees. The graduation commences at the freezing-point, and the boiling-point is the eightieth degree. It is still in general use in Russia.

The scale now generally adopted in France, was originally proposed by Celsius, and used in Sweden. It commences also at the freezing-point of water, between which and the boiling-point the space is divided into 100 parts: hence it is now commonly distinguished by the name of the centigrade thermometer (38).

Other divisions of the thermometric scale have at times been introduced, but have fallen into disuse.

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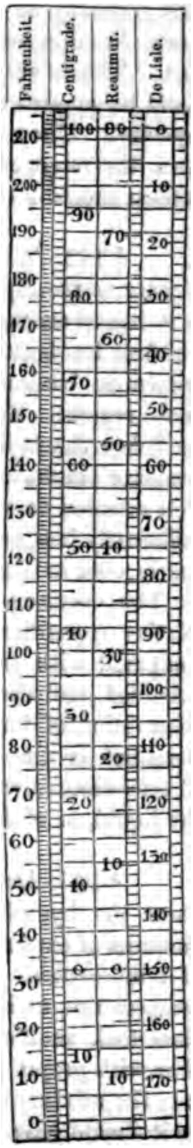
(38) These three divisions of the thermometer are laid down and compared in the annexed scale, together with another, by De Lisle, now in disuse, in which the space between the freezing and boiling-points

Fahrenheit's division is founded on error, and is very arbitrary and inartificial: it has, however, two important advantages:—1st, The degrees are small, and hence it is less requisite than with other scales to use fractional parts, which, in observation, are apt to be neglected, and in calculation are inconvenient. 2d, The commencement of the scale being placed at a low temperature, we have seldom to express negative degrees; while, in the centigrade and Reaumur's, it is always necessary either to prefix the signs of minus or plus, (− or +,) or by terms to denote whether the number stated is above or below Zero.



It would not be difficult in the present advanced state of science to invent a division of the thermometric scale which might at once be more philosophical and more convenient than any of those now in use; but nothing but the general consent of the leading scientific men in the principal countries where science is cultivated, would justify the attempt; which, without such an agreement, would only add to the perplexity and distaste which every one at times must feel from this multiplication of scales.

§ 141. It would be foreign to the object of this work to enter upon all the necessary refinement in the construction of a good ther-

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is divided into 150°, the Zero being placed at the latter.

Knowing the ratio of these scales to each other, nothing, of course, can be easier than to change the expression of their degrees from one to the other. Let it be required to know what 70° cent. is upon Fahrenheit's scale:

100 : 180 :: 70 : 126 and 126+32° (or the number of degrees from Fahrenheit's 0)=158.

Or what is 74° Réaumur upon the centigrade scale:

80 : 100 :: 74 : 92.5.

mometer; but every one should know how to test the goodness of instruments which everywhere abound. The principal point to be attended to is the equality of the bore of the tube; for if equal lengths have not equal capacities, of course a scale of equal parts will not divide the expansion equally. This may be ascertained by breaking off a portion of the thread of mercury in the tube, which may generally be done by a dexterous jerk, and moving it up and down the tube, ascertaining whether it occupy equal spaces in every part. This is very seldom, indeed, the case; but a correction may easily be applied to the scale by marking off upon it spaces of equal capacity. The examination of the fixed points is not difficult; but when the range of the scale will not admit of this, an accurate comparison should be instituted with a standard instrument.

§ 142. When great degrees of cold are to be measured, spirits of wine is the liquid selected for the construction of the instrument, as it has never yet been congealed by the greatest degree of cold to which it has been possible to expose it; whereas mercury has been known to become solid even in the natural temperatures of the arctic regions. Spirit, however, passes into vapour at a temperature far below the boiling-point of water; and it is usual, therefore, to graduate thermometers made with it, by comparison. Mercury is well adapted to most common purposes, as its congealing point is sufficiently low, and the upper part of its scale may be extended to nearly 600, in consequence of its high boiling-point.

The openness of the scale of a thermometer depends upon the relative capacities of the bulb and stem; the greater the former compared with the latter, the more the expanded liquid will be extended, and the larger will be degrees, and the more easy the observation of fractions of a degree. But the delicacy of the instrument, or the quickness with which it adjusts itself to changes of temperature, will depend upon the smallness of the quantity of the liquid, or of the matter upon which the change is to be effected.

§ 143. Dr. Brook Taylor was the first to confirm by experiment the hypothesis that equal thermometric degrees, or equal amounts of expansion, might be taken to represent equal increments of temperature. He took a pound of water, and heated it to the temperature, as indicated by a delicate thermometer, of 200°: he then took another pound, heated to 100°, and mixing the two together with proper precautions, he found that the thermometer plunged into the mixture indicated a temperature of 150°, or the exact mean; as it should have been according to the hypothesis.

§ 144. The expansion of solids is equally applicable with that of aëriform and liquid bodies to the measurement of temperature; but as it is smaller than that of matter in its other two states, and can only conveniently be measured linearly, and not in volume, it is by nice mechanical adjustments alone that it can be rendered available to the purpose. If a compound bar be formed by accurately adjusting and screwing together equal plates of two metals, whose expansions differ considerably,—such as iron and brass,—and one of its ends be fixed to some support; upon the application of heat it will bend, the least expansible metal becoming concave: if, on the contrary, the temperature be lowered below that at which the adjustment is made, the greater contraction of the brass will cause the iron to become convex. Upon this principle a very sensible thermometer has been constructed by M. Breguet. It consists of a very thin ribbon of platinum, plated with silver, and coiled into the form of a helix: one end of this compound plate is fixed to an upright support, and to the other a delicate index is attached, moving over a graduated circle. As the temperature to which this instrument is exposed varies, the spiral twists or untwists, and carries the index round the circle, the degrees of which measure equal amounts of the contraction or expansion. The value of the degrees may be fixed by comparison with a standard thermometer of the usual construction.

§ 145. The use of the mercurial thermometer is limited to temperatures below that at which quicksilver boils, or to about 600°; and a method of measuring the high temperatures of ignition at which many of the processes of the arts are carried on, having been long a desideratum of science, various methods have been proposed to supply the deficiency. The most celebrated *pyrometer* is that of Mr. Wedgwood. It consists of a metallic groove, or gauge, the sides of which gradually converge; pieces of very pure clay are made into small cylinders, having one side flattened; and, being heated to redness, they are made just to fit the larger extremity of the groove. It is a property of clay, permanently to contract and become harder by exposure to a high temperature: not that this contraction is an exception to the general law of expansion by heat, but is owing to a change in the chemical constitution of the earth, which loses a portion of the water with which it is combined, and it was supposed that the amount was exactly proportioned to the intensity of the heat to which it is exposed. The amount of contraction in the clay cylinders, after being exposed to the temperature which it was desired to measure, was easily determined by allowing them to slide from the top of the groove downwards, till they arrived at a point beyond which they would not pass. Mr. Wedgwood divided the whole length of this gauge into 240 parts or degrees, each of which he calculated to be equal to 130° of Fahrenheit's scale; and the Zero of his scale, indicating a red heat, corresponded, according to his experiments, to 1077°.

The difficulty of obtaining clay of uniform composition is of itself an almost insuperable objection to this method of estimating high temperatures; and it has been since ascertained that the observation upon which it is founded is not correct; for clay will contract as much by the long continuance of a comparatively low heat as by a short continuance of a high one. Hence the degrees of heat which Wedgwood's pyrometer has been applied to measure, have been enormously exaggerated.

§ 146. The problem, however, may be easily solved by the accurate measurement of the linear expansion of bars of metal in a pyrometer which was invented by the author, and called by him the *Register Pyrometer*.

It consists of two parts, which may be distinguished as the register and the scale. The register is a solid bar of black-lead earthenware, highly baked. In this a hole is drilled, into which a bar of any metal, six inches long, may be dropped, and which will then rest upon its solid end. A cylindrical piece of porcelain, called the index, is then placed upon the top of the bar, and confined in its place by a ring or strap of platinum passing round the top of the register, which is partly cut away at the top, and tightened by a wedge of porcelain. When such an arrangement is exposed to a high temperature, it is obvious that the expansion of the metallic bar will force the index forward to the amount of the excess of its expansion over that of the black-lead, and that, when again cooled, it will be left at the point of greatest elongation. What is now required, is the measurement of the distance which the index has been thrust forward from its first position; and this, though in any case but small, may be effected with great precision by means o. the scale.

This is independent of the register, and consists of two rules of brass, accurately joined together at a right angle by their edges, and fitting square upon two sides of the black-lead bar. At one end of this double rule a small plate of brass projects at a right angle, which may be brought down upon the shoulder of the register, formed by the notch cut away for the reception of the index. A moveable arm is attached upon this frame, turning at its fixed extremity upon a centre, and at its other, carrying an arc of a circle, whose radius is exactly five inches, accurately divided into degrees and thirds of a degree. Upon this arm, at the centre of the circle, another lighter arm is made to turn, one end of which carries a nonius with it, which moves upon the face of the arc, and subdivides the former graduation into minutes of a degree; the other end crosses the centre, and terminates in an obtuse steel point, turned inwards at a right angle.

When an observation is to be made, a bar of platinum, or malleable iron, is placed in the cavity of the register, the index is to be pressed down upon it, and firmly fixed in its place by the platinum strap and porcelain wedge. The scale is then to be applied by carefully adjusting the brass rule to the sides of the register, and fixing it by pressing the cross piece upon the shoulder, and placing the moveable arm, so that the steel point of the radius may drop into a small cavity made for its reception, and coinciding with the axis of the metallic bar. The minute of the degree must then be noted, which the nonius indicates upon the arc. A similar observation must be made after the register has been exposed to the increased temperature which it is designed to measure, and again cooled, and it will be found that the nonius has been moved forward a certain number of degrees or minutes (39). The scale of this pyrometer is readily connected with that of the thermometer by immersing the register in boiling mercury, whose temperature is as constant as that of boiling water, and has been accurately determined by the thermometer. The amount of expansion for a known number of degrees is thus determined, and the value of all other expansions may be considered as proportional.

§ 147. The melting point of cast iron has been thus ascertained to be 2786°, and the highest temperature of a good wind furnace about 3300°; points which were estimated by Mr. Wedgwood at 20577° and 32277° respectively.

Mr. Wedgwood, indeed, himself makes an observation which is calculated to throw suspicion upon the accuracy of his results, for he says, "We see at once how small a portion (of the range of heat) is concerned in animal and vegetable life, and in the ordinary opera-

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(39) 1. Represents the register; A is the bar of black-lead; *a a'* the cavity for the reception of the metal bar; *c c'* is the index, or cylindrical piece of porcelain; *d* the platinum band, with its wedge, *e*.

2. Is the scale by which the expansion is measured; *f f'* is the

tions of nature. From freezing to vital heat is barely $\frac{1}{100}$th part of the scale: a quantity so inconsiderable relative to the whole, that in the higher stages of ignition ten times as much might be added or taken away, without the least difference being discoverable in any of the appearances from which the intensity of fire has hitherto been judged of."

Now this is utterly unlike the gradual progression by which the operations of nature are generally carried on: and the fact is, that a regular transition may be traced from one remarkable point of temperature to another.

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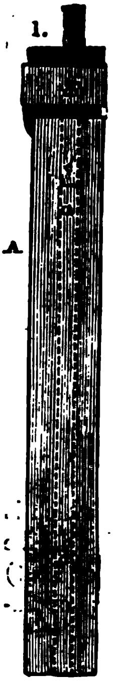
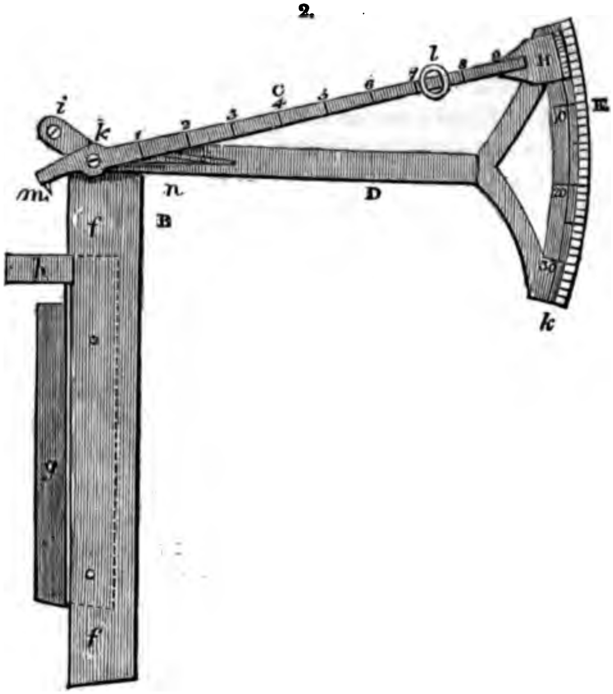
greater rule upon which the smaller, *g*, is fixed square. The projecting arm, *h*, is also fitted square to the ledge, under the platinum band, *d*.

1.



2.



D is the arm which carries the graduated arc of the circle fixed to the rule, *ff'*, and moveable upon the centre, *i*. C is the lighter bar, fixed to the first, and moving upon the centre, *k*. H is the nonius at one of its extremities, and *m* the steel point at the other.

Thus, from the freezing of water, 32°, to vital heat in man, is 60°.

$60 \times 3 = 180°$	. . . .	Boiling water.
$60 \times 7 = 420$	. . . .	Melting tin.
$60 \times 10 = 600$	. . . .	Boiling mercury.
$60 \times 15 = 900$	. . . .	Red heat.
$60 \times 31 = 1860$	. . . .	Melting silver.
$60 \times 45 = 2700$	. . . .	Melting cast iron.
$60 \times 55 = 3300$	. . . .	Highest heat of wind furnace.

§ 148. Being now in possession of accurate measures for the intensity of heat, we are prepared to proceed with our investigation of its effects upon solids, liquids, and aëriform bodies, we may drop the vague language of sensation,—of hot, and cold, and warm, and such like expressions,—and substitute the precise determinations of thermometric degrees.

It has been lately proved by the careful experiments of MM. Dulong and Petit, that beyond 212°, or the boiling-point of water, the expansion of solids, for equal degrees of heat, compared with that of air, increases as the heat rises; any differences in this respect between 32° and 212° being so small as to escape observation. The principal results of their investigation are shown in the following tables:—

TABLE VIII. *Increasing Dilatation of Glass by Heat.*

Temperature by an Air-Thermometer.	Mean absolute Dilatation of Glass for each Degree.	Temperature by a Thermometer made of Glass.
Fahrenheit.		
From 32° to 212°	$\frac{1}{69660}$	212
32° to 392°	$\frac{1}{65340}$	415.8
32° to 572°	$\frac{1}{59220}$	667.2

TABLE IX. *Increasing Dilatation of Metals by Heat.*

Temperature by Air-Thermometer.	Mean Dilatation of Iron, for each Degree.	Temperature by Iron-Rod Thermometer.	Mean Dilatation of Copper, for each Degree.	Temperature by Copper Thermometer.	Mean Dilatation of Platinum for each Degree.	Temperature by Platinum Thermometer.
212°	$\frac{1}{50760}$	212°	$\frac{1}{34120}$	212°	$\frac{1}{67860}$	212°
572°	$\frac{1}{40678}$	702°.5	$\frac{1}{31860}$	623°.8	$\frac{1}{65340}$	592°.9

It appears that at temperatures beyond 212°, glass expands in a greater ratio than mercury; and as the mercurial thermometer measures the *difference* of the expansion of the glass and metal, upon the supposition that they are both uniform, its degrees require a correction in the upper part of the scale, when compared with the equal dilatations of air. Thus the temperature of 586° on the mercurial thermometer, corresponds with 572° on the air-thermometer: while from the third column of Table VIII. it appears that the expansion of glass alone, supposed to be equable, would indicate 667° for the same point. The second, fourth, and sixth columns of Table IX. show the mean expansion, for each degree, of iron, copper, and platinum, when heated from 32° to 212°, compared with that from 32° to 572°; the third, fifth, and seventh columns indicate the degrees on thermometric bars of these metals, corresponding to the temperature of 572° on an air-thermometer.

§ 149. Before the invention of the register pyrometer, the expansion of solids had never been ascertained beyond the temperature of 572°; the following table exhibits the progressive amount of several metals to their points of fusion as determined by that instrument:—

TABLE X. *Progressive Dilatation of Solids.*

1000000 PARTS, AT 62°.

	At 202°.	At 662°.	At Fusing Point.
Black Lead Ware .	1000244	1000703	
Wedgwood Ware .	1000735	1002995	
Platinum	1000735	1002995	1009926 maximum, but not fused.
Iron (Wrought) .	1000984	1004483	1018378 to the fusing points of cast iron.
Iron (Cast) . . .	1000893	1003943	1016389
Gold	1001025	1004238	
Copper	1001430	1006347	1024376
Silver	1001626	1006886	1020640
Zinc	1002480	1008527	1012621
Lead	1002323		1009072
Tin	1001472		1003798

§ 150. The amount of the force which produces these expansions and contractions measured by any opposing force, that of cohesion for instance, is enormous. Some idea may be formed of it, when it is understood that it is equal to the mechanical force which would be necessary to produce similar effects in stretching or compressing the solids in which they take place; thus a bar of iron heated so as to increase its length a quarter of an inch, by this slow and quiet process exerts a power against any obstacle by which it may be attempted to confine it, equal to that which would be required to reduce its length by compression to an equal amount. On withdrawing the heat, it would exert an equal power in returning to its former dimensions.

Such a force as this is capable of being applied to a variety of useful purposes when properly directed, and of producing very injurious effects in constructions of art, when not properly provided against.

The wheelwright applies this power by making the iron band, or *tire* as it is called, of a carriage-wheel a little smaller than the wooden circle, or fellies, and then expanding it by heat, he fits it on to the latter. He afterwards suddenly cools it by throwing water upon it, and the contraction binds the whole together with enormous force. Upon the same principle the cooper heats the iron hoops of his casks, and firmly draws the staves together by cooling them in their places. The plates of the boilers of steam-engines are rivetted together with hot rivets, which, when cool, draw them together and render their junction perfectly compact.

M. Molard, by an application of the same force, ingeniously restored the equilibrium of a building in Paris, the walls of which had been pressed outwards by the incumbent weight. He introduced several strong iron bars through holes in the opposite walls, and screwed strong plates, or *washers* as they are called, on the projecting ends, so as to bear tightly upon the walls. The bars were then heated by lamps, and consequently lengthened; in this state the washers were again screwed up, and when the bars were allowed to cool, they contracted and drew the walls together to a small amount: a repetition of the same process gradually and safely effected the purpose.

The same process has been since applied in the restoration ot the Cathedral at Armagh.

§ 151. Experience has taught engineers that it is dangerous to attempt to confine such a force as this, and that it is necessary to make provision for these expansions and contractions, particularly in the metallic constructions which are now so common. In iron pipes for the conveyance of gas and water, when the lengths are very considerable, some of the junctions are rendered moveable; so that by the end of one pipe sliding into that of another, the accidental changes due to temperature are provided for.

The arches of the Southwark iron bridge rise and fall about an inch in the usual range of atmospheric temperature, and if provision had not been made for this, destructive consequences must have ensued.

The steeple of Bow Church has within these few years been nearly thrown down by the alternate expansion and contraction of some rods of iron which were built into it to give it stability. The rods in hot weather lengthened, and lifted the incumbent mass of masonry; they returned in cold weather to their former dimensions, leaving the stones upraised; dust and small particles of matter made their way into the cracks thus produced; the rods again lengthened, and lifted the mass a little higher; till, by numberless repetitions of this slow but irresistible operation, the fabric was shaken to its foundation.

Even in the shoeing of a horse, injurious consequences will follow from neglect or ignorance of this principle. If a horse shoe be applied in a heated state, the hoof will certainly be injured by its subsequent contraction.

§ 152. A singular circumstance accompanying the contraction of metal during great degrees of cold, was observed in some of the expeditions to the arctic regions, viz., that the astronomical instruments did not always, at once, take the adjustment due to the temperature to which they were exposed; but upon concussion they contracted suddenly to the regular amount.

§ 153. We have already noticed the greater expansion of liquids than of solids for equal increments of temperature, and the various amounts in different species. These expansions are generally regular, except when they are near their boiling or their freezing-points. Near the higher point, their expansibility increases rapidly for equal increments, while considerable anomalies have been observed near the lower.

It has been stated (§ 19.) that the law of expansion by heat, and contraction by cold, is all but universal; there is but one real exception to it known, and this occurs in water. It has been established by the most careful and decisive experiments, that water not only expands as we have noticed (§ 78.) when in the act of passing from the liquid to the solid state; in the moment, that is, when its particles are taking up a new and regular arrangement under the prevailing force of cohesion; but increases its volume in the act of cooling, some time before it reaches its freezing-point. This expansion commences when the temperature is reduced to about 40° of Fahrenheit, or eight degrees above the point of congelation, and it increases in an increasing ratio until the liquid solidifies.

The observation is easily made by means of two equal thermometers, the one filled with water and the other with spirit. When placed in melting ice, the latter will gradually fall to the freezing-point, while the former will descend to about 40°, and then begin to rise.

§ 154. From the alteration of volume which bodies universally undergo from changes of temperature, the necessity of attending to this circumstance in taking specific gravities will now be readily understood. These consisting of the weights of equal bulks of different kinds of matter compared with water, it is necessary that the temperature of the standard, and of the bodies with which it is compared, should be the same. The temperature of 60° has generally been adopted as a mean, which is most easily insured in all situations and in all seasons; but, unfortunately, practice is not quite uniform in this respect, and by Act of Parliament the temperature at which the specific gravity of spirits is determined by the Excise, and at which the standard weights and measures are adjusted, is 62°.

From the great dilatation which aëriform matter undergoes from increase of temperature, the correction of the measured volumes of different kinds of air is of the highest importance. It results from the accurate experiments of Dr. Dalton and M. Gay Lussac, that all experience equal expansions by the same augmentation of temperature, and that 100 parts of air at 32°, being heated to 212°, expand to 137.5 parts: the increase being $\frac{37.5}{100}$th of the original bulk.

Dividing this by 180, we find that a volume of air dilates $\frac{1}{480}$th of the volume which it occupied at 32°, for every degree of Fahrenheit's scale: the universality of this law, as applied to every species of elastic matter, not in contact with any liquid, has been proved by experiment with substances of the most opposite qualities, through a range of temperature extending from the freezing-point of water to the boiling-point of quicksilver. The application of this observation to the required corrections will be obvious with a little attention; though continual mistakes are made with regard to it. Let it be required to know what volume 100 cubic inches of air at 70° would occupy at 60°, or what contraction would take place by this change of 10°; we must bear in mind that it is not $\frac{1}{480}$th part per degree of the observed volume at 70° which is to be deducted, but $\frac{1}{480}$th part of the volume, which 100 cubic inches at 70° would occupy at 32°. Now 480 parts of air at 32°, become 481 parts at 33°, and increase one part for every additional degree, so that at 60° they have increased to 508 parts, and at 70° to 518 parts; and thus we have a proportion between the volumes at 60° and 70° by which we can determine the question, for

		Cb. In.	Cb. In.
480+38 :	480+28 ::	100 :	98.069.

Or, on the other hand, if we wish to know the correct volume at 60° of 40 cubic inches of air observed at 35°,

Vol. at 35°	Vol. at 60°	Cb. In.	Cb. In.
480+3 :	480+28 ::	40 :	42.07.

Again:—the weight of 100 cubic inches of air, being 31 grains at 60°, the weight of an equal volume at 212, will be found as follows—

Vol. at 212°	Vol. at 60°	Grs.	Grs.
480+180 :	480+28 ::	31 :	23.86.

In making this correction for temperature in addition to that for pressure, formerly noticed (§ 47.), it matters not which is first applied to the observed volume, as the result will be the same in either case.

§ 155. One of the most important properties of heat—for the accurate appreciation of which we are indebted to the thermometer, although it may be rudely estimated by mere sensation,—is its tendency to an equal diffusion or equilibrium. Twenty or thirty substances of different natures, all unequally heated, will speedily attain to an equality of temperature in a still atmosphere, and this equality is established by different processes, into the nature and laws of which it must be our business to inquire.

CONDUCTION OF HEAT.

§ 156. If we take a stick of charcoal, and hold it in the flame of a candle or lamp, we shall find no disagreeable sensation of heat, even when the red-hot extremity is at a very small distance from our fingers; but if we take a metallic wire and hold it in the same situation, it will speedily burn us at many times the distance from the hot extremity long before any part becomes red. The process by which the heat is conveyed along the metal is called *Conduction*. It thus travels through a body without changing the relative position of its adjacent particles. The law of this propagation is as follows:—If the extremity of a metallic bar be placed in communication with a constant source of heat, and we wait till it has taken up a permanent state of temperature, we shall find that for distances from the source taken in arithmetical progression, the excess of temperature above the surrounding medium will form a geometrical progression.

The property varies very much in different solids; and from the above experiment, we conclude that the charcoal is a bad conductor, and the wire a good conductor of heat. It may be roughly stated, that the most dense bodies possess the property in the greatest proportion. Thus metals are the best conductors; next stones; next hard woods, and so on.

TABLE XI. *Of Conduction.*

Gold	1000
Marble	23.6
Porcelain	12.2
Fine Clay	11.4

Diamonds and other gems are much better conductors of heat than glass, and thus may be distinguished from it by contact with the lips which, in general, are very sensible to changes of temperature. The former substances will feel cool when compared with the latter.

Metals themselves vary very much in their conducting power, so that if equal bars of silver and platinum be each held by one of their extremities, while the others are in contact with flame, the former will burn us while the latter will feel scarcely warm. The following table exhibits the conducting powers of different metals compared with gold:—

TABLE XII. *Of Conduction of Metals.*

Gold	1000	Iron	374.3
Silver	973	Zinc	363
Copper	898.2	Tin	303.9
Platinum	381	Lead	179.6

§ 157. We have already noticed the vagueness of any estimation of temperatures by comparing them with our own sensation; the different conducting powers of substances will discover a new source of erroneous judgment from this test. In a room of uniform temperature all the different inanimate substances may be of equal temperature, but if we touch substances of different densities and natures, very different sensations will be produced by them: a piece of metal will feel much colder than marble, stone, or glass; and these, again, colder than a wooden-table, or a book. The reason is obvious; each of these substances, although they would affect a thermometer equally, has a different conducting power; and that which is the best conductor will carry off heat from our bodies with the greatest rapidity, and therefore will produce in us the greatest sensation of cold.

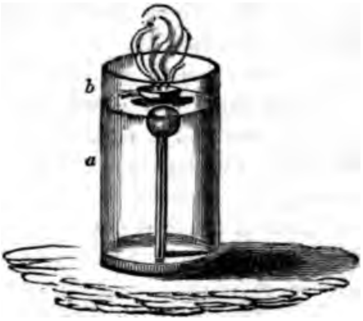
§ 158. Many useful contrivances for the convenient management of hot bodies are dependent upon the differences of this property; as when a wooden handle is applied to protect the hand from a hot tea-kettle, or the handle of a silver teapot is insulated from the body by the interposition of small plates of ivory, which effectually prevent the conduction of heat to any inconvenient extent.

By breaking the cohesion of solids their conducting power may be very much decreased, and on this account, by placing a layer of sand upon the hand, and carefully screening the surrounding parts, a red-hot iron ball may be supported without inconvenience. At the siege of Gibraltar red-hot balls were carried to the batteries in wheelbarrows, covered with sand.

§ 159. Liquids conduct heat with such difficulty, that it has been doubted by some philosophers whether they be not destitute of this power. From the facility, however, with which they acquire heat, under particular circumstances, it might be hastily concluded that they possess it in an eminent degree: but this facility depends upon another property which we shall presently examine. The imperfection of this property in liquids may be proved by a very simple and easy experiment. If we nearly fill a glass tube, four or five inches in length, with water, and heat the upper part in a spirit-lamp, we may cause the water to boil upon the surface, while we hold the tube in the hand without the slightest inconvenience, the water not being able to conduct the heat downwards. It may be proved with greater precision by placing an air-thermometer in a glass jar, and filling the latter with water, so as to cover the bulb with a layer of the liquid, not more than the tenth of an inch in depth. Oil of the temperature of 400° may now be carefully poured upon the surface; or a capsule of inflamed ether may be floated upon it without affecting the thermometer (40). The heat, however, will ultimately be conducted down the solid sides of the containing vessel; and the interference of this operation renders it difficult to make very accurate observations upon the subject; but it has, nevertheless, been proved by very delicate and ingenious experiments, that liquids do conduct heat, and differences in the power have even been detected in different liquids: mercury, for instance, being a better conductor than water, and water than oil.

§ 160. The difficulty of determining the power of conduction in aëriform bodies, is still greater than in liquids. It has never yet been proved that they are capable of conducting heat at all; and common experience even may convince us that they are very bad conductors. A very simple experiment may afford a rough estimate of the comparative powers of conduction in the three classes of solid, liquid, and aëriform bodies. Metals heated to 120° will severely burn a hand placed upon them, owing to the facility with which the heat will travel towards it; water will not scald, provided the hand be kept without motion in it till it reaches the temperature of 150°, while the contact of air may be endured at 300°. A thin layer of either the liquid or air is cooled by the contact, through which the heat of the adjacent particles travels with great difficulty; but if the hand be briskly moved about, and brought into contact with fresh particles, the water will be intolerable, at a much lower temperature.

There is an experiment upon record, in the Philosophical Transactions, by Sir Joseph Banks, and others, who ventured into a room heated to 260°, and remained there a considerable time without serious inconvenience: and in several processes of the arts it is



(40) *a* represents the vessel of water, with the included air-thermometer; *b* is the capsule containing the inflamed ether.

necessary for workmen to enter stoves heated as high even as 300°, from which no injurious effects follow. Under such circumstances, all contact with metallic substances must be carefully avoided, or severe injury would be sustained. The same property of non-conduction also preserves the body in the opposite extreme of temperature; and the late voyages to the Arctic regions prove that a cold of $-55°$, or 14° below that of freezing mercury, may be sustained without injury, provided the atmosphere be still; but if there be any wind, the successive contact of fresh particles, even at much higher temperature, will abstract heat with sufficient rapidity to freeze the extremities.

§ 161. The bad conducting power of the vapour of liquids is strikingly proved by heating a bright capsule, or crucible of platinum or silver, to nearly a white heat, and then throwing into it a few drops of water. The liquid will be collected into the form of a flattened sphere, under the force of cohesion, and will roll about upon its axis to different parts of the heated surface without wetting it, being kept from contact by an intervening atmosphere of vapour. Under these circumstances it will slowly evaporate, but will never reach its boiling-point. If the temperature, however, of the metal be allowed to fall, the liquid will come into contact with it, and will be converted into vapour with almost explosive violence.

The same phenomena are produced with water and heated iron; and another curious instance of the anticipation of science by common experience is afforded by the test which laundresses apply to ascertain the proper temperature of their smoothing-irons. When a drop of moisture, extemporaneously applied, rolls off the iron in a globule, they know that it is sufficiently hot; but when it adheres and boils, it is returned to the stove.

§ 162. Many useful applications are daily made of these principles, to the purposes of convenience, and of the arts. We put double doors inclosing a body of air, to our furnaces, to prevent the heat from being conducted outwards; and we double-case our ice-houses to prevent it from being conducted inwards. We act upon the same experience in the selection of proper substances for clothing, to preserve our animal warmth: and articles of dress are warm in proportion to the quantity of air which they contain in their texture; furs, feathers, wool, and down, retard the passage of heat in this way; and, for the same reason, snow preserves the warmth of the earth in frosty weather.

Count Rumford measured the relative conducting power of different materials employed for clothing, by enveloping a thermometer in a glass cylinder, blown into a ball at its extremity, and filling the interstices with the substance to be examined. He heated the apparatus in boiling water, and then transferred it into melting ice, and observed the number of seconds which elapsed during the passage of the thermometer through 135 degrees.

Air, alone required	576″	Raw silk	1284″
Lint	1032	Beavers' fur	1296
Cotton wool	1046	Eider down	1305
Sheeps' wool	1118	Hares' fur	1315

The unerring Wisdom which providently presides over the order of nature, changes the clothing of many animals as the seasons change: hair, at the approach of winter, being changed into wool, and feathers into down.

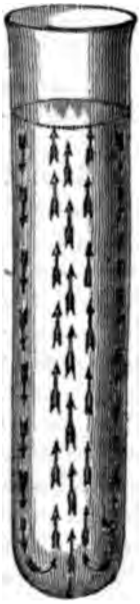
CONVECTION OF HEAT.

§ 163. EVERY one is aware that, notwithstanding the difficulty with which heat travels through liquid and aëriform matter, by the process of conduction, that is, without disturbing the relative position of adjacent particles, both classes of bodies speedily become heated, and that equilibrium of temperature is brought about which it is always the tendency of heat to operate and maintain. This is effected by processes of circulation—or rapid change in the relative position of adjacent particles,—and the process has been appropriately termed Convection.

When a liquid is heated we have seen that it expands, and, of course, becomes lighter; from its great mobility the heated and lighter particles rise to the surface of the mass, and a new portion comes into contact with the source of heat, rises in its turn, and so the whole is brought successively under its influence, and the motion will continue, as long as heat continues to be thus communicated. The rapidity with which heat is thus conveyed is easily illustrated by the simple apparatus of the water in the glass tube (§ 159). If, instead of applying, the flame of the spirit-lamp to the surface of the liquid, it be applied to the bottom, the whole mass speedily attains the boiling temperature, and becomes intolerable to the hand. The course of the currents by which the circulation is maintained is easily rendered visible by suspending some light powder, of about the same specific gravity, in water, in a glass flask (41). The more a liquid is expanded by a given change of temperature, the greater will be the difference of specific gravity between the part which is heated and the rest of the mass, and the more rapid therefore will be the circulation from the change. Any tenacity and viscosity in the liquid will impede its motion, and when water is thickened with flour, or other farinaceous substances, it parts with acquired heat very slowly: many a person, however, has burned his mouth with hot porridge, and expressed his surprise at the slowness with which it cools, without being able to assign the philosophical reason of the phenomenon.

The circulation of heated water is now commonly and advantageously applied as a safe, economical, and regular means of warming hothouses, and other buildings.

§ 164. The same process takes place, but much more rapidly, in elastic fluids; and in this class of bodies the equilibrium of heat is maintained by a circulation of the most perfect kind. Any one who has observed "the moats in a sunbeam," must have remarked by their motion, in almost every direction, the rapidity with which the ascending and descending currents of the air upon which they are borne, intermingle; and upon looking across a heated body, as a



(41) The direction of the ascending and descending currents, in a vessel of water heated from the bottom, is shown by the darts in this diagram. An ascending current sets up the axis of the cylinder, and is compensated by an equal quantity of liquid descending towards the circumference. If the heat be applied equally round the sides of the vessel, the direction of the currents will be reversed. The motion of the particles of light powder become very rapid, and the water is thus carried to its boiling-point.

chimney or a hot poker, the ascent of the heated column of air may clearly be detected.

The force with which it rises is indicated by the steady and tapering form of the flame of a candle, which consists of aëriform matter in a state of ignition. This heated current generally ascends perpendicularly in the surrounding cool medium, but may be diverted from its course by holding over it a long tube, in the axis of which it will flow, though greatly inclined from the perpendicular. The flame of a gas-burner may even be directed downwards by connecting it with the shorter arm of a tube, bent twice, at right angles. The longer arm must have the air within it rarified, by burning a little spirit of wine in a sponge, when an ascending current will be established, which will draw down the ignited gas, the heat of which will afterwards maintain the draught in the chimney.

§ 165. The expansive and ascensional force of a body of hot air may also be illustrated by confining it in a bag of any light material, such as tissue paper. If the aperture of such a bag be held over the flame of a piece of sponge, steeped in spirit of wine, it will become distended, and ascend in the air. Such was the power which Montgolfier first applied to the construction of a balloon, and in dependence upon this principle Pilatre de Rosier first committed himself to float upon the atmosphere.

§ 166. Some very interesting properties of aërial currents may be illustrated by placing a lighted taper in a flat dish, and covering it with a bell-glass, with a long chimney immediately over the flame. If a little water be placed round the edge of the glass, in the dish, the air will be prevented from entering under it, and the flame will speedily be extinguished for want of a fresh supply. If, however, the taper be again lighted, and the chimney of the bell-glass be divided into two channels by a diaphragm down the middle, and it be again placed over the taper, it will continue to burn for any length of time. The heated and light particles of the air, which tended to ascend in the tube in the former arrangement, but were impeded by the opposite tendency of the cold particles to descend, will pass out by an ascending current on one side of the diaphragm, while a contrary current of fresh air will continually compensate them on the other side; the direction of these currents is readily rendered visible, by mingling some cloudy or smoky substance with the descending current. This separation of contrary currents is of considerable importance in the ventilation of mines, and many deep shafts are divided by boarded partitions, to insure the descent of fresh air upon this principle.

We are indebted to the expansion of air for the ventilation of our rooms, and for the ascending currents in our chimnies, by which our fires are maintained. If we hold the flame of a candle to the upper part of a door, opening into a heated room, we shall not fail to find, by the direction in which it is bent, that a current of light heated air passes outwards; while, by lowering it to near the bottom, we shall be able to detect a counter-current of denser cold air rushing inwards with equal velocity.

The knowledge of these principles, it cannot be denied, ought to have led to a more perfect system of ventilation than is commonly adopted in our public buildings, where crowds assemble for business or for pleasure; but this, unhappily, is not the only instance in which indolence prefers the well-beaten road of routine practice to the more laborious paths which better knowledge would point out.

§ 167. The convection of heat is a process of the utmost consequence also in some of the grand operations of nature; and it is principally by the circulation of fluids, elastic and non-elastic, of which their perfect mobility renders them susceptible, that the distribution of temperature over the earth is regulated, and those great inequalities guarded against, which would certainly result from the heating of the solid strata alone. Thus the atmosphere with which the globe is surrounded, moderates the extremes of temperatures both in the arctic and equatorial regions. When the surface becomes heated by the direct rays of the vertical sun, the stratum of air reposing on it is rarefied and ascends; its place is supplied by the denser air pressing in from the colder parallels, and by a constant succession of these operations the heat is moderated, which would otherwise become intense. The constant current of the trade winds owes its primary impulse and direction to this cause. The constantly ascending warm air, in its effort to maintain that equilibrium and equality of pressure which results from the laws of hydrostatics, must flow over towards the colder climates, and carry with it the heat with which it is charged, and thereby mitigate the extremes of cold. Currents from the poles and the equator upon the surface of the earth, and opposite currents from the equator to the poles, in the upper region of the atmosphere, will therefore constantly exist, although their directions may be variously modified by inequalities upon the earth's surface, and other disturbing influences. The course of these grand compensating currents has often been traced by accidental circumstances. Some years ago, during an eruption of a volcano in the island of St. Vincent, in the West Indies, it was observed that the ashes were carried against the course of the winds: *i. e.*, against the course of the current upon the surface of the earth. The force of the explosion, or the ascensional force of the ascending column of heated air had, in fact, carried them into the upper stream, which was flowing in the contrary direction. Those also who have made the ascent of the Peak of Teneriffe, have constantly observed the wind blowing in the contrary direction on the summit, to that which prevailed at the foot of that mountain.

§ 168. Water is not less useful in this respect, in the economy of nature. When a current of cold air passes over the surface of a large collection of water, it abstracts from it a quantity of heat; the specific gravity of the water is thereby increased, and the cooled portion sinks. Its descent forces up a portion of warmer water to the surface, which again communicates heat to the air passing over it; and this process may be continued for a considerable time, proportioned to the depth of the water. Currents are also formed in the ocean similar to those in the elastic atmosphere. The water which descends, when unobstructed, must spread at the bottom of the sea, and the denser water of cooler latitudes will flow towards the equator, and produce compensating currents upon the surface in opposite directions; and thus the ocean again tends to moderate the excessive heats of the torrid zone, as well as the intense colds of the polar climates. The Gulf Stream, as it is named, is an example of this action. This great current sets across the Atlantic from the coasts of Africa, and being deflected from the shores of the Gulf of Mexico, is carried northwards to the banks of Newfoundland, in the neighbouring latitudes of which, it may generally be detected by its effects upon the thermometer. An immense volume of warm water is thus transported to the cold regions of the north, where it cannot but have a considerable influence upon the climate. It is probable that the temperature of the westerly winds of our own island in winter is much influenced by this cause.

§ 169. And here we must not fail to observe the important and beneficial purpose effected by that singular exception to the general law of expansion by heat, which fixes the point of greatest density in water nearly eight degrees above its point of congelation (§ 153). When the whole mass of accumulated fluid, such as that in a deep lake, has been cooled down to the temperature of 40° by the perpendicular circulation which we have just considered, the vertical movement ceases, and the surface water becoming lighter as the temperature further falls, soon sets into a sheet of ice. The subjacent water is preserved from the further influence of the cold by the cessation of the circulation, and its almost perfect non-conducting power. If, like mercury, oil, and other liquids, its density went on augmenting to its freezing point, the cold air would continue to rob the mass of its heat till the whole sank to 32°, and it would suddenly set into a solid rock of ice, and every living animal within it would perish. In these climates a lake so frozen could never again be liquefied; for the process of thawing necessarily beginning above, the heated and light water would lie upon the surface, and effectually prevent the convection of heat to the lower strata.

This observation is, however, only fully applicable to accumulations of fresh water: for the waters of the "great deep," another protection has been provided. Saline matter in solution in water, it has been ascertained, lowers both the point of freezing, and the point of maximum density. The ocean, on that account, and because of its great depth, which renders it an almost inexhaustible store of heat, resists freezing still more effectually than the deepest natural reservoirs of fresh water, and is scarcely known to freeze, except in latitudes where the most intense cold prevails. Even then, it is the watery particles alone which congeal to the exclusion of the saline, which, increasing the density of the lower strata, arrest their circulation, and thus preserve them from the superficial cold.

HEAT OF COMPOSITION.

§ 170. *Heat* and *Temperature* we have hitherto used as nearly synonymous terms, and all the effects of the subtle force, to which we have been directing our attention, have been accompanied by its free development, and have been measured by our sensations, and by the thermometer and pyrometer. We have now to trace it, entering, as it were, into the composition of bodies, losing its character of temperature, and becoming latent to our instruments and our feelings.

Equal volumes of the same liquid, at different temperatures, afford, upon mixture, the mean temperature of the two. A pint of water at 50°, being mixed with a pint at 100°, a thermometer immersed in the mixture will indicate a temperature of 75°. This result has already, indeed, been adduced in confirmation of the accuracy of the instrument (§ 143). If, however, a measure of quicksilver at 100° be agitated with an equal measure of water at 40°, the resulting temperature of the two will not be 70°, or the mean, but 10° lower, or 60°; so that the quicksilver will lose 40°, whereas the water will only gain 20°: yet the water must contain the whole heat which the quicksilver has lost. Hence, it appears that water has a greater capacity for heat than quicksilver: it requires a larger quantity of heat to raise it to a given temperature. The confirmation of this view may be obtained by the converse of the experiment; for if a measure of water at 100° be agitated with an equal measure of quicksilver at 40°, the resulting temperature will be 80°: the water will fall 20° in temperature, but in this fall will give out sufficient heat to raise the quicksilver 40°.

The same comparison may be made by weight, and will lead to the same conclusion. Thus, if a pound of quicksilver at 40° be agitated with a pound of water at 156°, the resulting temperature will be 152°.3: the water will lose 3°.7 of temperature, but enough heat will be evolved to raise the metal 112°.3. Now, the proportion of 3°.7 : 112°.3, is the same as 0.033 : 1; hence, adopting water as the standard of comparison, we call the specific heat of quicksilver 0.033, designating by the term *specific heat* the heat peculiar to the *species* of matter compared with the standard.

Again: If a pound of water at 100°, and the same weight of oil at 50°, be mixed together, the resulting temperature will not be the mean 75°, but 83°.5; the water, therefore, will lose 16°⅔, while the oil will gain 33°½, or reversing the temperatures, the mean will be 66°⅓, so that the oil will give out 33°⅓, and the water will rise only 16°⅔. Hence, the heat which will raise the temperature of oil 2°, will raise an equal weight of water only 1°; and the specific heat of oil will therefore be 0.5°.

§ 171. This different capacity of different bodies for heat must have a considerable influence upon their rates of heating or cooling: those which have the highest specific heat increasing or diminishing their temperatures most slowly under equal circumstances. Thus, if equal quantities of water and quicksilver be placed at equal distances before a fire, the metal will be more rapidly heated than the water; and again will cool down a certain number of degrees more rapidly when exposed in a cold place. Conversely, the specific heats of different bodies may be determined by carefully observing the time in which they cool down a certain number of degrees, and comparing them with water under similar circumstances. This method is susceptible of great accuracy, and may obviously be applied where mixture is impossible.

§ 172. A third method of ascertaining specific heats was devised by M.M. Lavoisier and La Place, who contrived an apparatus for the purpose, to which they gave the name of Calorimeter. This instrument was liable, however, to some practical objections, which have limited its use. The principle, upon which it was constructed, will afford another illustration of the nature of the phenomenon (42). A certain weight of water, for instance, was surrounded with ice in a convenient vessel, and in passing from the temperature of 212° to 32°, the quantity melted was found to be a pound; an equal weight of oil in cooling down through the same range of temperature thawed only half a pound: and from this experiment we arrive at the same conclusion, as from mixture and cooling, that the specific heat of water being reckoned as 1°, that of the oil is only 0.5°.

The following Table exhibits the specific heats of various bodies referred to this standard, from the best authorities:—

Table XIII. *Of Specific Heats.*

Hydrogen gas	3.2936	Oxygen	0.2361
Water	1.0000	Carbonic acid	0.2210
Aqueous vapour	0.8470	Charcoal	0.2631
Alcohol	0.7000	Sulphur	0.1850
Ether	0.6600	Iron	0.1100
Oil	0.5200	Mercury	0.0330
Nitrogen gas	0.2754	Platinum	0.0314
Air	0.2669	Gold	0.0298

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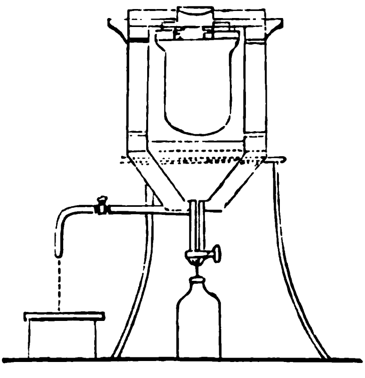
(42) The calorimeter consists of two similar metallic vessels, the one contained within the other, and kept separate by small pieces of wood. The interval between the two is filled with ice, broken small, and packed close. By constantly renewing this ice as it melts by the heat of the atmosphere, the interior vessel will be kept constantly at the temperature of 32°. The water which is formed is removed by a stop-cock placed at the lower part of the interval between the two vessels. Within the interior vessel another still smaller is suspended, formed of iron net, designed to hold the body to be cooled. The interval between this third vessel and the second is also filled with ice: and the water which this latter produces in melting, flows out of the lateral stop-cock into a vessel which receives it, that it may be accurately weighed.



§ 173. It has been shown by the careful experiments of M.M. Dulong and Petit, that the specific heat of bodies increases as their temperature rises; so that it requires more heat to raise them a certain number of degrees when at a high than when at a low temperature. The specific heat of iron, for instance, was found as set down in the following Table:—

TABLE XIV. *Specific Heat of Iron.*

From 32° to 212°	0.1098
——— 392°	0.1150
——— 572°	0.1218
——— 662°	0.1255

A similar law is maintained in other bodies, as shown in the following Table:—

TABLE XV. *Progressive Specific Heat.*

	Between 32° and 212°.	Between 32° and 572°.
Of Mercury	0.0330	0.0350
Zinc	0.0927	0.1015
Antimony	0.0507	0.0547
Silver	0.0557	0.0611
Copper	0.0949	0.1013
Platinum	0.0335	0.0355
Glass	0.1770	0.1900

§ 174. It is probably from changes effected in the specific heat of bodies that condensation or approximation of their particles is attended with elevation of temperature, and dilatation or expansion with the opposite effect.

When spirits of wine and water are mixed together in equal measures, it may be shown that the bulk of the mixture is less than that of the two liquids in their separate states; and, in consequence, the temperature rises so as to become sensibly warm to the hand. In the same way oil of vitriol and water contract on mixture, and so much heat becomes free, that some inflammable substances may be kindled, or water boiled, by its application. The sudden compression of air by the piston of a small syringe disengages heat enough to kindle tinder exposed to it: while compressed air suddenly allowed to expand will become so cold as to condense all the vapour, with which it may be mixed, in the form of a cloud. If a delicate thermometer again be suspended in the receiver of an air-pump, it will be found to sink during the process of exhaustion, and the cloud which commonly forms at the same time is owing to the same absorption of the heat of temperature.

§ 175. The increased capacity which air acquires by rarefaction has an important influence in modifying the temperature of the atmosphere. The air becoming rarer as it ascends, absorbs its own free heat, and hence becomes cold in proportion as it recedes from the surface of the earth, from which it chiefly derives its heat. The average depression of temperature has been found to be about 1° of Fahrenheit's scale for each 300 feet of ascent. By this constitution of the atmosphere heat, so to speak, is economised: for if, instead of thus being absorbed and laid up in store, it had remained free, it would soon have become dissipated and lost. Other most important purposes are also effected by the progression of temperature which this law of specific heat has a tendency to maintain, to which we shall presently advert.

§ 176. When matter undergoes one of the great physical changes, from the solid to the liquid, and from the liquid to the aëriform state, we find exemplifications of the phenomena of *latent heat.* As in these transitions a large quantity of heat is absorbed, combined, or fixed, so in the opposite changes from the aëriform to the liquid, and from the liquid to the solid state, heat is again liberated and becomes sensible.

It was Dr. Black, who about the year 1757, originally investigated the phenomena of latent heat with singular success, and his researches upon the subject rank amongst the most admirable efforts of experimental philosophy. The observation had, as has been before remarked (§ 139), previously been made that the freezing and boiling of water always took place at certain fixed temperatures; but it occurred first to Dr. Black, to inquire what becomes of the heat which in either case must keep continually flowing into the bodies whilst the processes are maintained.

Equal weights of water at 32°, and of water at 212° will, as has been before explained, produce on mixture the mean temperature of 122°: but equal weights of ice at 32°, and of water at 212° only produce, after the ice has melted, a temperature of 52: the water loses 160 degrees of temperature while the ice acquires only 20°; 140° degrees of heat are therefore expended in changing the state of the ice from solid to liquid. Dr. Black, from this and similar experiments, drew the conclusion that this portion of heat became latent in the water; which owes its fluid state to this latent heat. That this heat is not destroyed or annihilated, will appear from considering that water, exposed to a degree of cold far below the freezing point, will gradually part with its excess of temperature above that of the surrounding bodies, and become colder and colder till it reaches the freezing point; but will not descend below 32° till the whole has become ice, and yet it must continue yielding up heat at the same rate as before. There must therefore be within it a continued supply of heat to keep it up to this fixed point: the moment the whole becomes concrete, the temperature will begin to sink, and will soon reach that of the surrounding objects and medium.

§ 177. Similar phenomena are observable in all cases of liquefaction; and we can produce artificial cold often of great intensity by the rapid solution of certain saline bodies in water; upon this principle the action of freezing mixtures depends, which are often applied economically to the purpose of cooling beverages in hot climates. The mere solution of nitre alone will lower the temperature of water at 50° to 35° and four ounces of nitrate of ammonia, with four ounces of carbonate of soda, dissolved in four ounces of water at 60°, will in three hours freeze ten ounces of water in a metallic vessel immersed in the mixture whilst the solution is in progress. A mixture of equal parts of snow, or pounded ice and common salt, will sink the thermometer from 32° to 0°, or the point from which Fahrenheit commenced his thermometric scale, upon the mistaken notion that he had obtained the absolute zero of heat. It is this mixture which is commonly employed for freezing cream. From the rapidity with which salt and ice react upon one another and produce liquefaction, salt is often strewed upon the pavement of the streets when they become incrusted with hardened snow, and it is then easily removed. The thawing of the ice by the production of a greater degree of cold, might appear paradoxical to those who have not properly considered the steps of the process.

A mixture of three parts of muriate of lime and two parts of snow, will sink the thermometer from 32° to – 50°, a degree of cold sufficiently intense to freeze quicksilver. To produce the maximum effect, the salts should be newly crystallized, reduced to a fine powder and cooled to 32°, and the vessels in which the freezing mixture is made should be very thin. The mixture should also be made as rapidly as possible.

One of the most striking modes of illustrating the absorption of heat by liquefaction, is by the action of metallic bodies alone: if 207 parts of lead, 118 of tin, and 284 of bismuth be melted together and reduced to a fine state of division by pouring them into water, upon dissolving the alloy in 1617 parts of quicksilver, a thermometer immersed in the mixture will sink from 63 to 14, and water may be frozen by the process.

All liquids remain perfectly fixed at the temperature of their congealing points during the process of liquefaction, or as long as any of the substance remains in the solid form: their temperatures cannot rise, because all the heat to which they may be exposed is absorbed and rendered latent. The use of this point in water for the graduation of thermometers we have already noticed (§ 139).

§ 178. The following is a Table of the congealing points of various bodies, including a range of temperature from the boiling of water to the freezing of mercury, throughout which the law is maintained:—

TABLE XVI. *Of Congealing Points.*

Sulphuric ether	−46°	Acetic acid	50°
Mercury	−39	Tallow	92
Oil of turpentine	+14	Wax	149
Water	32	Sulphur	218
Olive oil	36		

The fusing or congealing points of metals in the higher ranges of the pyrometer, are equally fixed, and the temperature of melting iron or gold is invariable in the heat of the most powerful wind furnace, so long as any of the metal remains in the solid state.

TABLE XVII. *Congealing Points of Metals.*

Mercury	− 39°	Zinc	773°
Potassium	+136	Silver	1873
Sodium	194	Copper	1996
Bismuth, lead and tin alloy	212	Gold	2016
		Cast iron	2786
Tin	442	Iron and platinum above	3280
Bismuth	476		
Lead	612		

§ 179. The quantity of heat absorbed, or rendered latent by the fusion of various bodies, is not a constant quantity for all, but varies in different bodies; this is shown by the following results of the experiments of Dr. Irvine:—

TABLE XVIII. *Latent Heat of Liquids.*

Water	140°	Bees'-wax	175°
Sulphur	143.7	Zinc	494
Spermaceti	145	Tin	500
Lead	162	Bismuth	550

§ 180. When liquids, on the contrary, pass into the solid state, their latent heat becomes sensible; water, by careful management, as by exposing it in an undisturbed atmosphere to a freezing mixture with a little oil floating upon its surface, may be cooled several degrees below its freezing point without solidifying, but the moment that, by agitation or other means, it is made to congeal, it rises to the temperature of 32°.

If spirit of wine be poured into a saturated solution of sulphate of potassa, the salt is instantly precipitated in the solid form, and the temperature of the liquid rises so as to become sensibly warm to the hand. When water is poured upon quick-lime, a great degree of heat, and sometimes ignition, is produced, from the solidification which it undergoes in consequence of chemical combination. In short, congelation is at all times a heating, and liquefaction a cooling, process, to all surrounding bodies.

If we pursue the relations of matter and heat under the next change of physical condition, we shall find the same laws maintained in the passage of a body from the state of a liquid to that of a vapour, and in the contrary operation of passing from the aëriform to the liquid condition. There is no more clear and convincing mode of exemplifying the phenomena than by reference to the common still and worm-tub. During the whole process of ebullition in the still, when once the liquid has attained its boiling-point the temperature never rises above that point: notwithstanding the constant action of a strong fire it never varies, but all the heat is absorbed, and fixed by the process of vaporization. The water in the worm-tub, on the contrary, becomes hotter and hotter during the passage of the vapour again into the liquid state, and unless the cold water were constantly renewed, the process could not be carried on. The vapour, in fact, acts the part of a carrier of the heat, taking it from the fire and delivering it up to the water.

The heat given off by steam, during its condensation, is now commonly applied to the warming of buildings, and is at once safe, salubrious, and economical.

§ 181. If the process of vaporization had not been thus progressive,—if the constitution of a liquid had been such, that upon reaching a certain temperature it would have been at once converted into the aëriform state, the boiling of a tea-kettle would have been a service of imminent danger; the whole volume of water would have at once flashed into steam, with explosive violence.

Such a danger is, in fact, incurred upon distilling oil of vitriol, without great caution. The specific heat of the vapour of this acid is very small, and hence, when it begins to boil, sudden explosions of dense vapour rush forth from time to time, and the glass retort is liable to be broken by the concussion.

Every liquid, when of the same degree of purity, and under equal circumstance of atmospheric pressure, has one specific point at which it invariably boils:—thus, pure water boils at 212°; spirits of wine, of the specific gravity of .813, at 173°; ether, at 96°, when the pressure of the atmosphere, as indicated by the barometer, is thirty inches: that is to say, at those respective temperatures their several vapours attain an elasticity equal to that of the incumbent atmosphere, and they are enabled by the slightest impulse to act upon the air in mass, and to remove its obstruction to their course.

§ 182. The decrease of the atmospheric pressure enables vapour of lower degrees of elasticity to overcome its resistance, and hence liquids boil at lower temperature when it is diminished. Under the receiver of an air-pump water may be made to boil at the temperature of 32°: that is to say, the pressure may be reduced till the vapour of water at that temperature, which is of no higher degree of elasticity than would be sufficient to support a column of mercury in the barometer of 0.20 inches, would be sufficient to remove it, but the full amount of latent heat must be absorbed in its passage into the aëriform state.

If some ether be placed under the receiver of the air-pump, and an arrangement made by means of a sliding-rod, by which a small flask of water, covered with some bibulous substance, be alternately dipped into it, and removed, when the exhaustion is made the ether will boil rapidly, and absorbing the heat of the water, will cause it speedily to congeal.

Mercury may even be frozen by the same process, by substituting sulphuret of carbon for the ether. The rapid evaporation of water is carried on with the greatest facility under diminished pressure, especially if the steam which is formed be condensed during its formation, so as to remove the resistance of its elasticity. Upon this principle depends an ingenious mode of freezing water in common atmospheric temperatures, devised by the late Sir John Leslie. For this purpose some substance which rapidly absorbs the vapour of water, such as oil of vitriol, (dried basaltic rock,—or dried oatmeal will answer the purpose,) is placed in a flat dish upon the plate of the air-pump, over this is supported upon a glass trivet a capsule of glass, containing a little water, and a delicate thermometer, and the whole is covered with a low glass receiver; when the vacuum is made, a very instructive series of phenomena ensue. The water is speedily seen to boil, or give out large bubbles of steam, and the thermometer begins to fall very rapidly, denoting that the free heat, or heat of temperature, is rapidly absorbed during the process of vaporization. This steam is instantly absorbed by the oil of vitriol, which becomes hot by the evolution of the latent heat of the steam during its return to the liquid state, and in a short time the whole remainder of the water is converted into a cake of ice (43).

Another beautiful illustration of the same principle is afforded by a little apparatus of the late Dr. Wollaston, which was named by him the *cryophorus*, or frost-bearer. It consists of two bulbs of glass, connected together by a long stem of glass, and containing water. The water is boiled in one of the bulbs till the included air is expelled by the generated steam, through a small aperture in the other bulb, which is then sealed at a lamp; when cool, the pressure of the included steam is reduced to that due to the temperature of the air: if the empty bulb be now surrounded with a freezing mixture of snow and salt, its elasticity again falls, and rapid evaporation takes place from the water in the distant ball,

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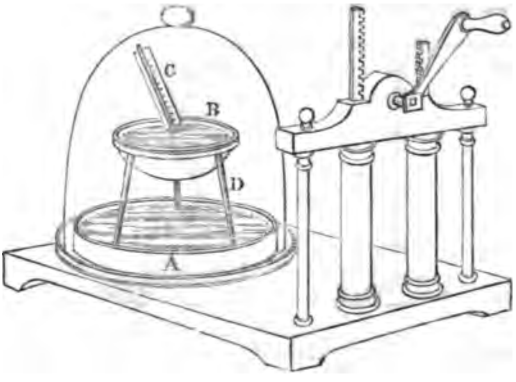

(43) A is the glass dish which contains the acid; D the trivet supporting the glass capsule, B, three parts filled with water; and C the thermometer, to show the progress of the refrigeration.

which is soon converted into ice by the rapid abstraction of its heat of temperature (44).

§ 183. The rapid evaporation of water at low temperatures, under diminished pressure, has been taken advantage of in the arts, in certain processes where vegetable products are liable to injury from exposure to high temperatures. Thus the manufacture of sugar has been improved in the process of Mr. Howard, by which the boiling of the syrup is carried on in close pans, from which the air is extracted by means of the air-pump: and the preparation of vegetable extracts is effected without any danger of burning, by Mr. Barry's process, in close vessels from which the air is expelled by steam, the elasticity of which is afterwards reduced by cold water. The distillation of spirits is also effected by similar means, without the danger of imparting an empyreumatic flavour to the products.

§ 184. In consequence of the diminished elasticity of the air in the upper regions of the atmosphere, the boiling-point of liquids is lower on the tops of mountains than at their bases; and water boils at the summit of Mont Blanc, at the temperature of 187°. The late Archdeacon Wollaston invented an apparatus upon this principle, which is applicable to the measurement of heights. It consists of a mercurial thermometer, with a very large bulb, dipping into a small portable boiler, which is readily heated by a spirit-lamp. By means of a vernier the 1000th part of a degree may be read off upon the scale; and although such a thermometer would but slowly follow, and imperfectly indicate changes of atmospheric temperature, in consequence of the large quantity of the mercury to be heated,

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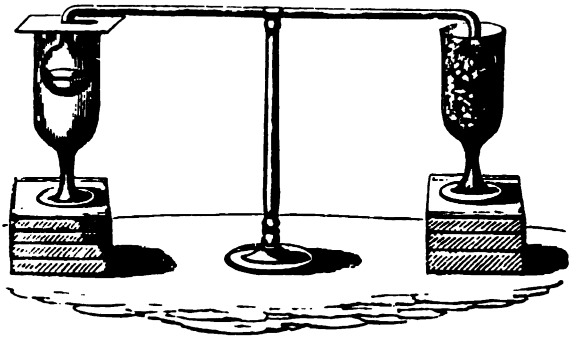
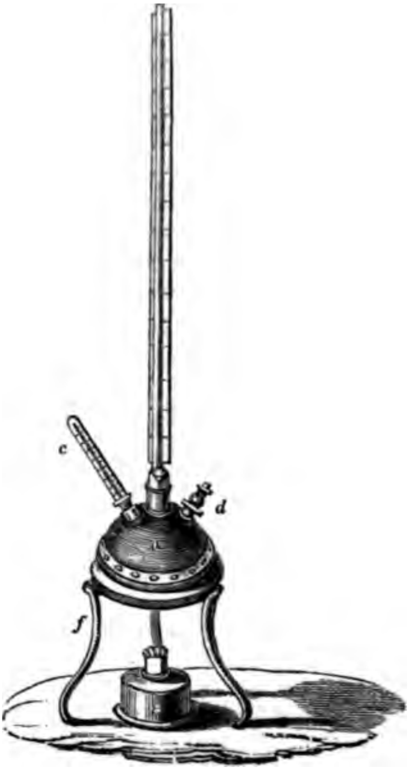
(44) This figure represents the Cryophorus, arranged for the experiment, with one of its balls immersed in the freezing mixture.



the permanency of the boiling-point of water easily permits of its being exposed to it for a sufficient time to ensure its full effect. He found that a difference of barometric pressure of 0.589 inches, was equivalent to 1° in the boiling-point, or 530 feet of ascent; and that the difference of the height of a common table from the ground would produce a difference in the boiling-point, which was clearly indicated by the instrument.

§ 185. It follows from the principles which we have just established, that under a pressure greater than that of the atmosphere, liquids must require a higher temperature to make them boil, —to make them generate vapour of a force equivalent to that pressure. If water be enclosed in a small boiler, at the bottom of which some quicksilver is placed, into which an open barometer-tube may be plunged after passing through a tight packing-box, and the bulb of a thermometer be immersed in the water through a similar packing-box, it may be made to boil. The steam being allowed to escape into the air through an open stop-cock, the thermometer, under these circumstances, will indicate the usual temperature of 212° (45). If the stop-cock be then closed, the elastic force of the confined steam will gradually increase; and, reacting upon the surfaces of the water and quicksilver, will raise a column of the latter in the barometer-tube, or gauge, which by its height will measure the elasticity of the



(45.) *a* is the strong brass globe, composed of two hemispheres screwed together with flanches; *b* is the barometer-tube passing through the steam-tight collar; *c* is the thermometer, graduated to 400°, and also passing through a steam-tight collar *d*; is a stop-cock, and *e* a spirit-lamp. The whole is supported upon the brass stand, *f*.

rising vapour: as the column ascends the temperature will augment, and when it attains the height of thirty inches, denoting that the atmospheric pressure is doubled, the thermometer will indicate the temperature of 250.5.

The subject has recently been examined by a commission of the Academy of Sciences at Paris, at the head of which were M.M. Dulong and Arago; they obtained the results set down in the following Table, by actual experiment, to twenty-five atmospheres,—or a pressure of 375lbs. upon the square inch, and extended it by calculation to fifty atmospheres:—

TABLE XIX. *Force and Temperature of Steam.*

Atmos.	Temp.	Atmos.	Temp.	Atmos.	Temp.
1	212°	10	358°.88	19	413°.78
2	250.52	11	366.85	20	418.46
3	275.18	12	374.00	21	422.96
4	293.72	13	380.66	22	427.28
5	307.5	14	386.94	23	431.42
6	320.36	15	392.86	24	435.56
7	331.70	16	398.48	25	439.34
8	341.78	17	403.82	——	——
9	350.78	18	408.92	50	510.60

§ 186. The solvent powers of water are greatly increased by the elevation of temperature which may be communicated to it by pressure; and this property was turned to economical account in Papin's digester, which consists of a boiler, fitted by means of wedges, with a close cover, in which is a safety-valve, which, being loaded with weights, only yields when the internal pressure exceeds a certain amount. This apparatus has recently been employed for the extraction, upon a large scale, of the gelatinous and albuminous matter which abounds in bones, and the product has been applied to the purposes of nutrition. As the temperature of steam is always that of the liquid producing it, and may be accurately regulated by the degree of pressure, high-pressure steam is often applied with great advantage when a steady heat may be required.

§ 187. The following is a Table of the boiling-points of several liquids, under a mean barometric pressure of 30 inches:—

TABLE XX. *Of the Boiling-points of Liquids.*

	Fahren.		Fahren.
Ether, sp. gr., 0.736, at 48°	100	Water	212
Sulphuret of Carbon	113	Oil of turpentine	316
Alcohol, sp. gravity 0.813	173.5	Sulphuric acid, sp. gr. 1.848	600
Nitric acid, sp. gr. 1.500	210	Mercury	655

§ 188. Having seen that a large quantity of heat is absorbed, or becomes latent, in the passage of a liquid to the aëriform state, and is again given out by its recondensation, it becomes an interesting subject of inquiry, to ascertain the quantity which thus enters into combination. Dr. Black approximatively determined this for water by a very simple experiment. He placed two cylindrical flat-bottomed vessels of tin-plate of similar dimensions, containing equal measures of water at 54°, upon an iron-plate, which was kept heated. He noted that in four minutes the water began to boil, and in twenty minutes the whole had evaporated. In four minutes, therefore, the water had received an augmentation of temperature of 162°, or 40½° in each minute, by which it was carried up to its point of ebullition; calculating that the heat continued to enter the water at the same rate during the whole time of boiling away, he concluded that 810° (or 40½ × 20) was carried off, and became latent in the steam. Dr. Henry contrived an apparatus by which the experiment may be made with much greater precision. It consists of a close boiler, with a thermometer, from which a bent tube proceeds, which may be made to dip into a measured quantity of water in another vessel, and in which the steam may be condensed (46). Supposing the latent heat of steam to be 900°, a quarter of a pint of water raised to steam in the boiler, would, by recondensation into water, raise the temperature of an equal quantity in the condenser

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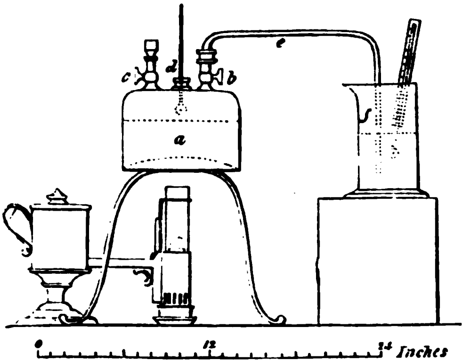
(46) *a* is the copper boiler in which the measure of water is placed, *d* is a thermometer plunged into the same, *c* is a stop-cock, *b* is another stop-cock opening a communication with the bent tube, *e f*, plunged beneath the surface of the measured water in another vessel, the temperature of which is to be raised by the condensation of the steam.



900°, if it were possible, or what is equivalent to this, ten quarter-pints, 90°, which result is easily obtained. One gallon of water, converted into steam at the ordinary pressure of the atmosphere, will by condensation raise five gallons and a half of ice-cold water to the boiling-point. The best and most careful experiments agree in fixing the latent heat of steam between 900° and 1000°.

§ 189. The latent heat of different vapours differs, as we have found the heat of fluidity to differ, in various liquids. The following is a Table of the latent heat of steam and some other vapours, by Dr. Ure:—

TABLE XXI. *Latent Heat of Vapours.*

Vapour of Water, at 212°	1000°
„ Alcohol	457
„ Ether	312.9
„ Oil of turpentine	183.8
„ Nitric acid	550
„ Ammonia	865.9
„ Vinegar	903

§ 190. The density of steam (*i. e.*, the weight of a given volume) increases directly as its elastic force, upon the same principle that the density of air increases with the pressure to which it is exposed; and the same weight of steam contains, whatever its density may be, the same quantity of heat; its latent heat being increased in proportion as its sensible heat is diminished or absorbed. The principle admits of explanation by the following supposition:— Let us imagine that in a cylinder furnished with a piston, we have a certain quantity of steam, and that it is suddenly compressed by a stroke of the piston into half its bulk, without being reduced to the liquid state; it would acquire double elasticity, and its temperature would be increased. If we either suppose the cylinder incapable of transmitting heat, or take the moment instantly following the compression, before any heat has had time to escape, it must be evident that the sensible and latent heat together, before the compression, are precisely equal to the sensible and latent heat, after the compression; but in the dense steam the sensible heat is increased, and the latent heat diminished by equal quantities. Reversing this imaginary experiment, if we suppose only half the cylinder to contain steam at 212°, and the piston to be suddenly raised so as to double its volume, the density of course will be reduced to half, and its temperature will fall; but its sensible and latent heat together will remain unchanged.

The fact was long ago experimentally determined by Mr. Watt; but the experiments of M.M. Clement and Desormes present us with the following more accurate results:—

A certain weight of steam at 212°, condensed at 32°, gives out . .	180°	Sensible heat.
	950	Latent.
	1130	
The same weight at 250°	218°	Sensible.
	912	Latent.
	1130.	
The same weight at 100°	68°	Sensible.
	1062	Latent.
	1130.	

M. Despretz ascertained that the same law holds good with other vapours.

§ 191. When water is converted into steam, it undergoes a much greater expansion of volume than any other liquid hitherto examined. It expands eight times as much as sulphuric ether, and nearly three times and a half as much as alcohol. Thus the vapours of ether and alcohol are heavier than that of water, although the former, in their liquid states, are lighter than the latter. The increase of volume which certain of the commoner liquids undergo, when converted into vapour of the ordinary elasticity of the air, is set down in the following Table:—

TABLE XXII. *Of the Increase of Volume from Vaporization*

1 cubic foot of water = 1689 cubic feet of vapour.
1 cubic foot of alcohol = 493.5 ,,
1 cubic foot of ether = 212.18 ,,
1 cubic foot of spirits of turpentine = 192.15 ,,

§ 192. It has sometimes been hastily concluded, from the less latent and sensible heat of the vapours of alcohol, ether, and turpentine, that they might be used advantageously as generators of mechanical force, instead of the steam of water; but in this case their comparatively small expansion has been overlooked. Their cost in fuel would be proportionate to the latent heat of equal volumes.

Latent Heat.
A cubic foot of water yields 1700 cubic ft. . . = 1000°
A cubic foot of alcohol yields 493 cubic ft. = 457°
And 493 cubic ft. : 457 :: 1700 : . . . 1575°
A cubic foot of ether yields 212 cubic ft. = 312°
And 212 : 312 :: 1700 : . . . 2500°
A cubic foot of spirits of turpentine yields
192 cubic ft. . . . . . = 183°
And 192 : 183 :: 1700 : . . . 1620°

So that if alcohol, ether, and spirits of turpentine could be procured for nothing, it still would be much cheaper to employ water for the generation of steam for the purpose of obtaining mechanical power.

§ 193. A remarkable fact has been observed respecting steam of great elasticity, viz., that when suffered to escape suddenly from a cock or small aperture in the boiler, the hand may be held close to the orifice from which it is rushing violently, without being scalded by it, though common experience has taught most persons that steam of ordinary density scalds severely under similar circumstances. A part of this diminution of temperature may be owing to the sudden expansion which the steam undergoes when released from confinement, and which probably absorbs a portion of the heat evolved during its return to the liquid state; but its chief cause is its sudden and forcible mixture with cold air at its first rush. A large quantity of air is thus violently drawn along with it in its course. Dr. Young long ago proved that a stream of air, or vapour, or smoke, issuing gradually into the atmosphere, penetrates further in an unbroken column than a stream issuing with violence; in the latter case the elastic fluids become immediately mixed, from the violent action and reaction which takes place.

The working of the steam-engine depends upon the elastic force of steam, communicated by heat, and the instantaneous annihilation of that force by cold. The first principles of this machine are prettily illustrated by the simple apparatus of Dr. Wollaston, which we have already described (§ 66).

§ 194. Vapour, however, is not only formed from liquids at their boiling points under the pressure of the air, and at lower temperatures when that pressure is lessened or removed, but is constantly rising from their surfaces in the progress of spontaneous evaporation. Common experience has taught every one that water evaporates into the atmosphere at all temperatures, however low, and the same process takes place with other liquids. Dr. Faraday has, indeed, shown that vapour rises from mercury at common temperatures, at least from 60° upwards, although its elasticity is so very low, as not sensibly to depress the height of the mercurial column in the barometer. He placed some quicksilver in the bottom of a glass phial, to the stopper of which he attached a piece of gold-leaf, which speedily became white, from the amalgamation of the gold with the vapour which rose. If five barometers be prepared for the purpose, and a little water be thrown up into the air-free space of the first, a little alcohol into the second, ether into the third, and sulphuret of carbon into the fourth, each column will be depressed by the elastic force of the vapour of each liquid at the existing temperature of the air; and the amount of the depression may be determined by comparison with the column of the fifth barometer, into the vacuum of which no liquid has been introduced. The tension of the vapours increases with the temperature, provided the whole space in which they are diffused be heated to an equal degree; but by heating the liquids, by the warmth of the hand or otherwise, they may be made to boil, without increasing the elasticity of the vapours, which are condensed as soon as formed. The following Table exhibits the force and the weight of a cubic foot of steam at different temperatures:—

TABLE XXIII. *Of the Force and Weight of Steam at different Temperatures.*

Temperatures.	Inches of Mercury.	Weight of Cubic Foot.
		Grains.
32°	0.216	2.53
40	0.280	3.23
50	0.400	4.53
60	0.560	6.22
70	0.770	8.39
80	1.060	11.33
90	1.430	15.00
212	30.000	257.218

§ 195. Evaporation to the same degree takes place under the pressure of the atmosphere, but is entirely confined to the surface of the liquid, and is therefore proportional to the surface. If the surface of water be covered with oil, its evaporation is altogether stopped. In some places on the south coast of England, as in the Isle of Wight, sea-salt is obtained by allowing sea-water to evaporate spontaneously in large tanks; the process is afterwards completed by boiling down the brine which has thus been concentrated. In parts of Germany the same process is carried on with saline springs; but the evaporating surface is largely increased by pumping up the water to a great height, and then suffering it to percolate through immense stacks of brush-wood faggots. Evaporation does not proceed so rapidly when the air is still as when it is agitated by a brisk wind; and the more rapid the current of air the more rapidly, *cæteris paribus*, does the water disappear. When the air is calm, the vapour as it forms rises perpendicularly, but rests upon the surface of the water; and it is the pressure of its own vapour upon the surface of a liquid, and not the pressure of the gaseous atmosphere, which puts a stop to the process.

§ 196. The rate of evaporation increases also with the temperature, and the elastic force of the vapour given off, increases in a geometrical progression with equal increments of sensible heat. The following is a Table of the force of vapour at different temperatures, and the rate of evaporation per minute from a circular surface six inches in diameter, according to the experiments of Dr. Dalton:—

TABLE XXIV. *Of the Force of Vapour and Rate of Ecaporation per Minute.*

Temp. Fahr.	Force.	Calm.	Breeze.	High Wind.
	Ins. of Merc.	Grs.	Grs.	Grs.
212°	30.000	120.00	154.00	189.00
85	1.235	4.92	6.49	8.04
75	0.906	3.65	4.68	5.72
65	0.657	2.62	3.37	4.12
55	0.476	1.90	2.43	2.98
45	0.340	1.36	1.75	2·13
35	0.240	0.95	1.22	1.49
25	0.170	0.67	0.86	1.05

These amounts of evaporation are, however, only maintained when the incumbent air is perfectly dry, when no vapour pre-exists in it. If vapour be already present, as is always the case in the atmosphere of this climate, the quantity capable of evaporating at any given temperature will be the quantity indicated in the table, diminished by the quantity already incumbent upon the water.

§ 197. Various instruments have been invented for measuring the quantity of vapour existing in the atmosphere; or its relative degrees of dampness and dryness: they have been denominated hygroscopes and hygrometers. Many of them, as already noticed (§ 88), are founded upon the property which certain substances possess of imbibing vapour under the force of heterogeneous adhesion, and having their dimensions thereby altered. Upon the most celebrated of these, that of De Saussure (fig. 23), an enormous amount of labour has been bestowed both by its inventor and by M. Gay Lussac, to render the observations made with it comparable like the degrees of the thermometer, and to calculate the real amount of moisture which the equal degrees indicated. But it is liable to considerable uncertainty in its construction, and infallibly becomes deteriorated by time; its use has been discontinued except at the Paris Observatory, and more certain means have been substituted for measuring the hygrometric state of the atmosphere.

M. Le Roi, and afterwards Dr. Dalton, adopted a very simple and accurate method of determining the elastic force of vapour at any time existing in the air. It is founded upon the well-known property that the moisture of the atmosphere will condense itself upon the surface of a colder body in contact with it.

When a bottle of wine is brought from a cool cellar, or a glass on a summer's day is filled with water fresh drawn from a deep well, it becomes dewed upon the surface. By pouring such cool water into another glass, then carefully drying the surface of the first, and returning it and repeating the operation as often as may be necessary, the water becomes slowly warmer, and Dr. Dalton carefully marked with a delicate thermometer the temperature at which the dew just ceased to form, and this he appropriately denominated the *dew-point.* It is in fact the temperature of water which would yield vapour of the precise elasticity of that upon which the observation is made; and all the relations of such vapour being known, the observation is applicable, with certainty, to the determination of every question that can be proposed concerning it. Even in winter-time, or in very dry situations, a sufficient reduction of temperature may be produced in the liquid by the frigorific effects of the solution of salts, to produce the effect of precipitation. The observation is rendered more precise by using small bright metallic vessels, upon the cool surface of which the dew is most visible.

§ 198. To facilitate the observation of the dew-point the author, some years ago, contrived a hygrometer which has been extensively used in every part of the globe with certainty and advantage*. It consists of two small glass bulbs, connected together by a glass tube, bent twice at right angles in the manner of the cryophorus (fig. 44). A very delicate thermometer is enclosed in one bulb, which, being filled with ether, is heated till the vapour issues with full force from an aperture in the other, which is then hermetically closed. If the operation has been well performed, upon taking the bulb which contains the liquid in the hand, after it has cooled to the temperature of the surrounding air, it will boil, *i. e.*, vapour will be abundantly generated by the heat of the hand, which will be simultaneously condensed in the other cool bulb. The empty bulb is then to be covered with a piece of fine muslin, and when ether is dropped upon it, the volatile liquid will evaporate and cool the covered bulb. This exterior evaporation will cause condensation of the vapour of the internal vapour, and the ether included in the further bulb will immediately begin to evaporate, and cool its exterior surface. The fall of the interior thermometer will mark the degree of the falling temperature, which must be noted as the dew-point, at the moment that a slight ring of dew, just coincident with the surface of the liquid, forms upon the glass. The temperature will still continue to fall some degrees, but a confirmation of the observation may be obtained by observing the thermometer when it again begins to rise, and noting the degree at which the ring of dew again disappears. The two observations seldom differ more than a degree or two, and the mean may be depended upon as accurate: for the errors, if any, must lie in opposite directions (47).

§ 199. By means of the dew-point accurately ascertained, many points of the utmost interest to chemical and meteorological science may be determined.

By mere inspection of tables properly constructed, we can at once determine the elasticity and density of the aqueous vapour—its weight in a cubic foot of the air—the degree of dryness either upon the thermometric or the hygrometric scale, and the rate of evaporation; when the air is saturated, the precipitation is instantaneous, *i. e.*, the dew-point coincides with the temperature of the air. In this country, the degree of dryness measured in thermometric degrees seldom reaches 30°, that is to say, the dew-point is seldom 30° below the temperature of the air, but in the Deccan, with a temperature of 90°, the dew-point has been seen as low as 29°, making the degree of dryness 61°.

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(47) The two thin glass bulbs, *a* and *b*, are connected together by the bent tube, *c*. The arm, *b c*, contains the small thermometer, *d*,

* DANIELL'S *Meteorological Essays*, p. 139.

The more accurate mode, however, of expressing the moisture of the air from an observation of the temperature and dew-point, is by the quotient of the division of the elasticity of vapours at the real atmospheric temperature, by the elasticity at the temperature of the dew-point: for, calling the term of saturation 1000, as the elasticity of vapour at the temperature of the air is to the elasticity of vapour at the temperature of the dew-point, so is the term of saturation to the observed degree of moisture. Thus, with regard to the observation in the Deccan,

$$1.430 : 0.194 :: 1000 : 135.$$

The fourth term is the degree of moisture on the hygrometric scale.

§ 200. There is another method of estimating the opposite states of dryness and moisture, and that is by measuring the degree of cold produced by evaporation. Water does not evaporate at all when the air is saturated with moisture, *i. e.*, when the incumbent steam is of the full force of that which is due to the temperature; and the freedom with which the process proceeds at other times is in proportion to the dryness of the air, that is to say, to the differ-

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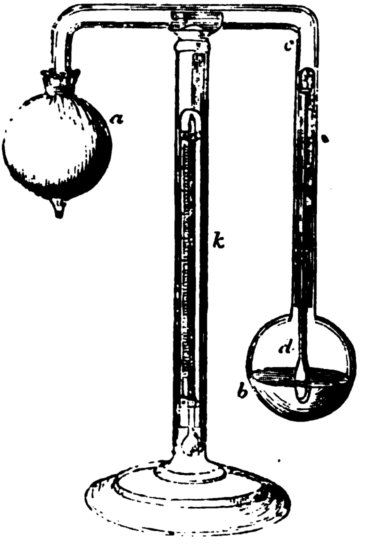
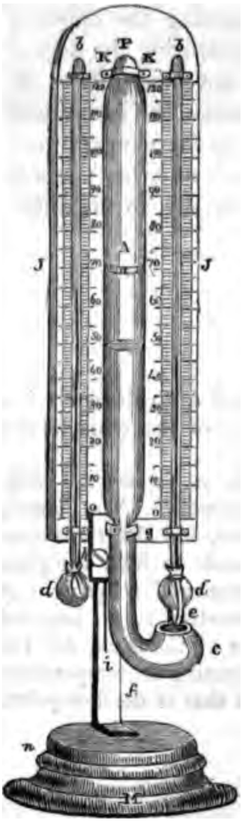


whose elongated bulb descends below the surface of the ether in the bulb, *b*.

The bulb, *a*, is covered with a piece of muslin. The stand, *g h*, is of brass, and the transverse socket, *i*, is made to hold the glass tube in the manner of a spring. A small thermometer, *k*, is inserted into the pillar of the stand for the purpose of comparing the temperature of the air with that of the dew-point.

ence of the force of the existing vapour and that which might exist at the temperature of the air. Dr. Hutton was the first to propose the observation of the depression of temperature caused by wetting the bulb of a thermometer as a measure of the rate of evaporation, and consequently of dryness. Sir John Leslie afterwards adapted a differential thermometer to the purpose: his hygrometer consisted of a delicate air-thermometer, one of the bulbs of which was covered with muslin and was kept continually wet by the dropping of water from a vessel by its side. A scale was adapted to it, to divide the space which the liquid was depressed by extreme dryness, into 1000 equal parts.

These degrees are arbitrary, and the depression is more simply expressed in degrees and fractions of a degree of the thermometric scale, and there are many adaptations of the thermometer for facilitating the observation. The method is decidedly superior to the hygroscopes already referred to, as correct data may probably be derived from it for calculating the dew-point and the degrees of saturation; but it requires corrections from calculation, for variations of temperature, pressure, &c., upon which philosophers and mathematicians are not yet agreed (48).



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(48) The most convenient apparatus for making this observation, is the contrivance of Dr. Mason. Upon the stand M is fixed an upright rod of brass, *f*, supporting the scale J J, in the middle of which a space is left to receive a glass tube, A, formed on the principle of the bird-fountain, having on each side of it a thermometer, *b b*. The bulbs of these thermometers are covered with white silk, but round the stem of one, a thread of floss-silk, *e*, is attached, which terminates in the cup of the fountain, *c*. This bulb being thus in connexion with a reservoir of water, is kept wet by capillary attraction; and as evaporation is constantly taking place, its temperature is reduced below that of the other bulb.

§ 201. This property with which water has been endued, of spontaneous evaporation at all temperatures, even below its freezing point, is one of the most important in the whole economy of nature: for upon it the growth of plants and the existence of all living creatures upon the earth depends. The vapour thus rising continually, not merely from the surface of the sea, lakes, and rivers, but also from the land in different states of moisture, is again condensed in the upper regions of the atmosphere, and falls in the state of hail, rain, or snow. Restored to the liquid state, it penetrates into the strata of the earth, and makes its way out again in springs: these collecting together constitute rivers, which, under the force of gravitation, descend to the sea, and complete the grand process of distillation and circulation.

The ultimate processes of evaporation and condensation tend also to that distribution of heat over the globe which we have already noticed as so essential to the well-being of the organic creation. Heat is thus carried in its latent state to the upper regions of the atmosphere, and is there given out in its free state by the condensation of the steam; and upon this silent and never interrupted process mainly depend the fluctuations of the aërial ocean, which tend so greatly to its salubrity, and which produce the observed variations of the barometer.

§ 202. The cause of these perpetual oscillations has long been a subject of investigation with philosophers, and many erroneous explanations have been given of the phenomena. The problem, in all its generality, is difficult and complicated, and may scarcely, perhaps, be deemed to belong to the department of chemistry. Without, however, going into the details which belong to meteorological science, it is desirable that an accurate notion should be formed of the true cause of the barometric changes, to which such constant reference must be made in many of the most important chemical operations. It has already been pointed out (§ 167.) that, owing to the unequal distribution of heat upon the surface of the globe, and the gradual decrease of temperature from the equator to the poles, the elastic fluids of the atmosphere must perpetually circulate between the colder and the hotter points; flowing from the former to the latter on the surface of the earth, and returning from the latter to the former in upper opposite currents. Now it is clear that, if such be the fact, the barometer weighs the pressure of these two combined currents at any given point; and so long as they balance one another, that is to say, so long as an equal quantity of air is brought by one stream to the base of the perpendicular column, to that which is carried off by the opposite from its summit, so long will their combined pressure be unchanged. But should any cause, partially acting, check the course of one, without at the same time impeding that of the other, the balance will be destroyed, and the barometer, by its rise or fall, will mark the amount of the disturbance. Owing to various causes, but chiefly to the unequal distribution of water and land, the course of the winds is by no means so regular as assumed above, but this grand system of compensating currents certainly results, although masked by circumstances in particular regions; most of these, however, give rise to minor systems of compensating currents, to which, as concerns the barometer, the same remarks will apply. Any one, indeed, may convince himself that such systems prevail in the atmosphere, by watching the progress of the clouds; and in this way he will often be able to detect more than two such currents existing together. Now, while he is observing their courses, let him for a moment suppose that the barometer is perfectly stationary, and then let him imagine one of the streams of air before him suddenly checked; the others will continue to flow on for a time in their primary direction from their inertia, and in obedience to their original impulse, and the barometer, he will conceive, must fall, because more air is carried off above it than is compensated by the current which originally maintained the balance; and as a deficiency may be thus produced in one part of the atmosphere, an equivalent accumulation must at the same time result in some other part (49).

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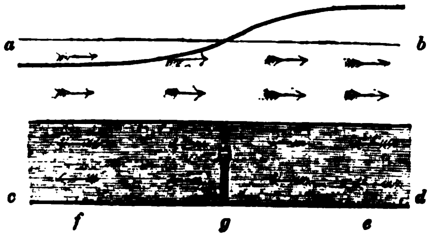
(49) Let *a b c d*, in the annexed diagram, represent two currents flowing in the opposite directions, indicated by the darts: a barometer placed in the lower at *g*, will support the pressure of both, and remain without oscillating so long as the two currents remain unchanged. But if a partial expansion affecting the upper current alone should urge it forward on its course on one side, and check it on the other, an accumulation of the nature of a wave would take place at *b*, and a corresponding deficiency at *a*, as indicated by the curve *a b*, and would be accompanied by a rise of the barometer at *g*, and a corresponding fall at *f*.



A cause, quite competent to produce these partial effects, exists in the atmosphere of steam mingled with the atmosphere of permanent gases, and which is constantly rising from the surface of the earth varying in force with the temperature of the waters from which it emanates. This vapour rises unchanged and transparent till, in the gradually decreasing temperature of the air, it arrives in the upper regions at a degree of cold by which it is condensed, and becoming visible, assumes the form of clouds. In the act of condensation, however, an immense quantity of heat is set free, which was previously combined with the steam in the latent form; and this acting upon the surrounding air, whose capacity for heat is small, expands it, and gives an additional but unequal impulse to the current in which the process takes place. The clouds, again, are themselves subject to a new evaporation, and the vapour is carried to still higher regions, where another precipitation takes place; till at length large masses of the atmosphere have the natural progression of their temperature changed, and their currents altered, or perhaps reversed. The increased temperature of the air is accompanied by a great increase in the force and quantity of the steam, the final precipitation of which takes place in the form of rain, and the atmosphere returns to its mean state through the influence of winds which restore the original balance. The order of the phenomena corresponds with the facts that the barometer is most steady when the weather is clear, and fluctuates most with clouds and rain; and also explains the reason why, in the greater disturbances of the aërial ocean, local deficiencies of the elastic fluid are restored by winds whose force is generally proportioned to the vacuum which they supply [*].

§ 203. The practical operations of chemistry often require a correction to be applied to the volume of gases for moisture, as well as for variations of pressure and temperature; for when standing over water they become mixed with aqueous vapour in a proportion dependent upon the temperature, and occupying the same space as when the gas is absent. The elastic force of the vapour causes the gas to expand; but this expansion is not precisely similar to that occasioned by heat: for while it dilates its bulk, it adds its own weight to the mixture. By reference to tables founded upon calculation upon the force and density of steam at different temperatures, the amount of the correction may be easily ascertained; or it may be more instructive to calculate it from the following data.—

Suppose we found 100 cubic inches of a gas saturated with vapour properly corrected for the temperature of 60°, and 30 inches pressure to weigh 31 grains, and wished to know the equivalent bulk and weight of the dry gas. The observed volume is partly due to the expansion occasioned by the vapour; and this portion will be in the same proportion to the whole as the elasitcity of the vapour is to the total elasticity: therefore,

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[*] DANIELL's *Meteorological Essays*, p. 559.

$$30.000 : 0.560 :: \overset{\text{Cub. In.}}{100} : \overset{\text{Cub. In.}}{1.86};$$

the volume of the dry gas is, therefore,

$$100-1.86=\overset{\text{Cub. In.}}{98.14}.$$

Now this expansion of 1.86 cubic inches may be regarded as so much vapour of the same elasticity as the air diffused through the whole space, and as the specific gravity of such steam compared to air is 0.620 : 1.000;

$$\text{then } 1 : 0.620 :: \overset{\text{Grs.}}{31} : \overset{\text{Grs.}}{19.22} \text{ (100 cubic inches steam),}$$

$$\text{and } \overset{\text{Cub. In.}}{100} : \overset{\text{Grs.}}{19.22} :: \overset{\text{Cub. In.}}{1.86} : \overset{\text{Gr.}}{0.35};$$

which gives the weight of the vapour to be deducted from the total weight: making the weight of 98.14 cubic inches of dry air,

31. − 0.35, or 30.65.

§ 204. Aërial fluids are commonly distinguished into two classes, viz., vapours and gases; but the experiments of Dr. Faraday have nearly annihilated the distinction, and proved that the difference is one of degree only, and not of constitution. In vapours, strictly so called, such as the steam of water, the latent heat is retained in combination with very little force; for it abandons the water when the vapour is exposed to a lower temperature; but in gases, the heat of composition is retained very forcibly, and no diminution of temperature that has ever been produced can separate it from some of them. Dr. Faraday has, however, succeeded in reducing to a liquid state many of those substances which till very recently were considered as permanently elastic fluids. His method is to generate them under strong pressure, by confining the substances from which the gases are evolved in strong glass tubes, in which their elasticity is allowed to increase till it forces their particles within the verge of cohesive attraction, when they assume the form of liquids. This operation he further assists by the application of cold mixtures to the exterior of one extremity of the tube. When thus produced, they continue liquid while the pressure is kept up, but on removing the pressure, instantly pass into the gaseous state. The same condensation may also be produced by mechanical force, and considerable quantities of carbonic acid have been thus reduced to the liquid state by Mr. Brunel, with the view of applying its expansive power as a mechanical agent. The cold produced by the sudden evaporation of these liquids is so great as actually to preserve some of the substances in their liquid state under the mere pressure of the air, and carbonic acid has been even frozen by the cold produced by its own spontaneous evaporation. Mr. Brunel was the first to observe this fact, and the loss of elastic force thus occasioned was, it is believed, the cause of giving up the attempt to construct a gas-engine.

§ 205. More recently, some very interesting results have been obtained by M. Thilorier, who has ascertained that the expansion of liquid carbonic acid for every degree of heat exceeds that of the acid in the gaseous state even by four times, and the pressure of the vapour from 32° of Fahrenheit to 86°, rises from 36 to 73 atmospheres.

A jet of liquid carbonic acid sinks the thermometer to 130° Fahrenheit below 0°.

It has little capacity for heat, and from its want of conducting power, its cooling effects alone do not correspond with the depression; but when mixed with vapour of ether, M. Thilorier succeeded in forming a cold blow-pipe, which froze 800 grains of mercury in a few seconds.

§ 206. A gas, then, may be regarded as the vapour of a liquid whose elasticity, at ordinary atmospheric temperatures, is such that it is not only equivalent to the pressure of the ordinary atmosphere but to that of many atmospheres, and which would therefore boil under the pressure of many atmospheres, and cannot consequently be preserved except under artificial pressure. The pressure required to condense the several gases is recorded in the following Table:—

TABLE XXV. *Liquefaction of Gases.*

	Pressure in Atmospheres.	Temperature, Fahrenheit.
Sulphurous acid	2	45°
Chlorine	4	60
Cyanogen	4	60
Ammonia	6½	50
Sulphuretted hydrogen	17	50
Carbonic acid	36	32
Muriatic acid	40	50
Nitrous oxide	50	45

Many gases have hitherto resisted the utmost degree of compression and cold to which it has been practicable to expose them, but from the generality of the law, its universality is a legitimate deduction; and geologists are justified in speculating upon the existence of the atmospheric gases themselves in a state of liquidity, in the fathomless depths of the earth, under the enormous pressures to which they must there be necessarily exposed.

Some gases, however, though incoercible, or requiring very high degrees of force to coerce them, by mechanical means and cold, instantly yield to the force of heterogeneous adhesion, and as they become dissolved in water, give out their latent heat. Thus, if a current of muriatic acid gas be passed into water, it will be rapidly absorbed, and the temperature of the solution will rise considerably.

§ 207. We have seen that water and other liquids gradually expand in volume with increase of temperature, and that, on the other hand, steam and other vapours rapidly increase in density, as the pressure and temperature, to which they are exposed, augments; whence it is clear that, at some particular assignable point, the liquid and elastic states must coincide, and that there must be a limit beyond which a liquid, notwithstanding the pressure, ought to be wholly volatilized, or become gaseous, provided sufficient space be allowed for the expansion. M. Cagniard de la Tour, reasoning upon the general facts, was led to make some interesting experiments upon the subject. A strong glass tube, containing alcohol equal in bulk to about two-fifths of its capacity, being hermetically sealed and carefully heated, the alcohol was observed to expand, till after having attained nearly double its original volume, it suddenly disappeared; being converted into vapour so transparent, that the tube appeared to be completely empty. Allowing it to cool, the alcohol was again suddenly converted into the full volume of liquid. When the proportion of alcohol to the capacity of the tube was increased, the consequence was the bursting of the tube. Similar results were obtained with naptha and ether, the latter requiring less space than the former for assuming the complete elastic state, and the naptha less space than alcohol. The ether became gaseous at a temperature of 320°, and exerted a pressure of 38 atmospheres; alcohol at 404½° under a pressure of 129 atmospheres.

Upon trying the experiment with water, the glass tube broke from its solvent power at the high temperature: but when this action was prevented by the addition of a little carbonate of soda to the liquid, it became gaseous in a space four times its volume at the temperature at which zinc melts.

§ 208. We have hitherto considered heat as inseparable to matter,—differing, however, from other forces in its slow progression amongst its particles,—tending, indeed, to an equilibrium, but still capable of existing in various degrees of intensity in different parts of the same mass. Differing, again, in the latent and apparently inactive state in which it becomes stored up in various forms and kinds of matter, and from which, though temporarily lost to our sensation and to our instruments, it may be again set free in full measure and proportion.

We have now to contemplate this subtle agent, detaching itself from matter, and projecting itself through space, and through various kinds of matter, with a velocity almost inconceivable.

We recognise heat in this wonderful state from the effects of a fire, or a heated body, at a distance. The warmth which we feel, or the expansion which we may observe under such circumstances, cannot be communicated by any material particles; for we may so contrive the experiment, that the air, the only form of matter which intervenes, may flow towards its source instead of from it.

It is also by this new property of *radiation*, that heat tends to that state of equilibrium which, upon a former occasion, we found to be partially established by the processes of *conduction* and *convection*.

But we recognise it in greatest perfection as projected from the sun: in which case it is accompanied, in all its affections, by another active influence of a still more marvellous constitution, which we call LIGHT. These two constant associates of the sunbeam radiate in all directions from the glorious centre of our system, and spread themselves through space with an intensity decreasing like that of gravity as the squares of the distance.

Though associated together, however, these radiant forces are not inseparable: and before we proceed to investigate the laws of *radiant heat*, it will be most convenient to illustrate those of light, with which they are connected by the strongest analogies.

LIGHT.

§ 209. The cause of that impression upon our eyes, which excites in us the sensation of light, is like that of heat, to be traced to various sources. The sun is the great fountain, not only of heat, as we have already remarked, but of this twin emanation from it to the earth, and to all the members of the solar system.

It emanates, also, from terrestrial matter in different states of activity. It is thrown off when certain homogeneous substances act upon one another by the mechanical force of friction; thus when two pieces of quartz or rock-crystal, or two lumps of loaf-sugar, are rubbed together, they emit flashes of light in a dark place.

It is generated in still greater abundance when heterogeneous bodies act upon one another under the force of chemical affinity; and all the common means of artificial illumination by lamps, candles, and gas-lights, are dependent upon this action.

All solid bodies, also, heated to a temperature of about 800°, begin to shine in the dark; and if a current of air at 900°, which is in itself nonluminous, be made to strike upon pieces of metal, earth, &c., it will speedily communicate to them the power of radiating light.

The passage of electricity excites it with a degree of intensity, only surpassed by that of the solar ray: and the processes of life are capable of evolving it as we see in the glow-worm and the fire-fly.

210. Bodies in such state of action are called self-luminous; but by far the greatest number possess no such property at ordinary temperatures. All bodies, however, though not luminous in themselves, nor capable of exciting any sensation in our eyes, become so on being placed in the presence of a self-luminous body. When a lamp, for instance, is brought into a dark room, not only the lamp is visible, but all the other objects in the room. A sunbeam, again, admitted into a darkened chamber, will only illuminate objects directly in its course; but if any of these be white, as a sheet of paper, the whole apartment will become illuminated by this secondary action or radiation. We have this fact illustrated on the most splendid scale of nature, in the heavenly bodies.—The sun we have just recognised as the great self-luminous source of the system: the moon and planets possess no such inherent energy; but those parts of them on which the sun shines become for the time luminous, and perform all the offices of self-luminous bodies. Thus we perceive that the communication which we call *light* subsists not only between luminous bodies and our eyes, but between luminous and nonluminous bodies, or between luminous bodies and each other.

§ 211. The investigation of the properties of light constitutes the peculiar province of OPTICS; one of the most splendid and perfect departments of experimental science which the human mind has explored; it lies, however, almost wholly out of our present path; but, in its relation to different forms and kinds of matter, light ought not to be excluded from the chemist's contemplation, and it is absolutely necessary that he should have some acquaintance with the laws which govern its action.

The phenomena lend themselves so completely to mathematical investigation,—they have afforded such ample scope for the exercise of the most splendid talents, from the times of Newton and Euler to our own times of Herschel, Airy, and Brewster,—that it seems almost sacrilege to approach them by any other path. But still the basis of this science, as of all other branches of natural knowledge, must be experiment; and those who are but moderately conversant with the powerful resources of abstract science have it in their power to draw information from this source, and methodise it in such a way as may serve to embody definite, though it may be rude, ideas, with regard to this most beautiful of all natural agencies,—ideas which may be highly useful, though they may differ from the polished conceptions of such men as those to whom we have just referred, much in the same degree as light itself differs from the grosser forms of ponderable matter.

§ 212. It is not consistent with our present design to enter upon the physiological relations of the subject, or to describe the wonderful construction of the organ of sight; we will only remark, that the radiant force produces the sensation of light by striking against the expanded nerve of vision, the retina of the eye, and that the effect produced is not merely transient, but persistent during a measurable interval of time. The eye has therefore the power of retaining visual impressions for a sensible period of time; and in this way recurring actions, made sufficiently near to each other, are perceptibly connected, and made to appear as a continued impression. Hence it is that the act of winking with the eyelids forms no impediment to correct vision.

It has been ascertained by experiment that the impression which the mind thus receives lasts for about the eighth part of a second; so that any point of light revolving with a velocity sufficient to complete the circle within that time, will not be seen as a fiery point, but as a fiery circle; the impression made by it in every part of its revolution, will remain until it comes round again to the spot from which it set out. Thus, if a narrow slit be cut in a circle of pasteboard, from the circumference to the centre, and it be held before the eye, and made to spin rapidly upon its axis, objects will be seen through it as if it were wholly transparent, and only covered with a thin gauze. Many familiar appearances are explicable upon the same principle, and, amongst others, the magical effects of fireworks, in which revolving jets of flame produce the impression of continuous wheels of fire. Several beautiful illustrations of it have also lately been contrived in the form of toys, which are well calculated to excite wonder, and it is to be hoped a somewhat more rational curiosity with regard to their construction.

§ 213. There are two hypotheses with regard to the nature of light, which have hitherto divided the opinions of philosophers.

The hypothesis of *emission* supposes that light consists of a highly attenuated fluid, the particles of which are not affected by gravity, but are endued with a prodigious self-repulsive force, and are actually projected from luminous substance in right lines, with inconceivable velocity. We seem to form some notion of matter in such a state when we contemplate the direct rays of the sun. The rectilinear course of the light is shown by particles of floating dust, or minute drops of water, which are illuminated in its course, and mark the unvarying direction of its progression.

In the hypothesis of *undulation*, on the contrary, the whole universe, including the interstitial spaces of all matter, is conceived to be filled with a highly elastic, rare medium, which possesses the property of inertia, but not gravitation, to which the name of *ether* has been given. This medium is not light, but light is produced in it by the excitation on the part of luminous bodies of an undulatory motion, analogous to the waves of water, or those vibrations of the air which produce the impression of sound upon the ear.

§ 214. And here it is quite necessary to correct any erroneous judgment which may have been formed from careless observation of the manner in which force propagates itself in bodies which are capable of this kind of oscillation. A wave does not consist, as is often hastily supposed, of any advance or progression of the particles of which it is composed in the direction in which they appear to run; the particles, it is true, move, but in a direction transverse to their apparent motion. In contemplating the phenomena in a still sheet of water, the force of a falling pebble, or the slightest brush of a summer's insect, will be sufficient to excite a system of waves spreading from the impinging body as from a centre. Certain particles are at first forced down, and the surrounding particles are consequently heaped up above their level; this circular ridge subsides, but not only fills up the original depression, but, from its momentum, forces up another ridge exterior to it, and this, in subsiding, another, and so on; and thus the force is propagated, and advances from the centre with a decreasing energy.

Vibrations are propagated through elastic bodies upon exactly the same principle, only that it is the force of elasticity which, by its alternate action and reaction, produces the oscillating wave, instead of the momentum of the liquid particles.

The analogy between the supposed undulations of the ether, which produce light, and those of the grosser particles of our ponderable atmosphere, which produce sound, is so striking, that the undulatory theory has received some of its happiest illustrations from experiments conducted by means of the measurable vibrations of musical notes.

The direct propagation of light finds its parallel in the propagation of sound along a solid elastic medium. Professor Wheatstone has shown, in a most beautiful series of experiments, that when a tuning-fork (fig. 12) is placed at one extremity of a long conducting-rod of metal, glass, or wood, while the other communicates with a sounding-board, the sound is heard as instantaneously as when it is in immediate contact with the board; it immediately ceases when the rod is removed from the sounding-board, or the fork from the rod. The vibrations are inaudible in their transmission, and only become sensible at the point where they are multiplied by meeting with a sonorous body placed to receive them. All the varieties of tune, quality, and audibility, and all the combinations of harmony, from different musical instruments, may be thus transmitted unimpaired, and again rendered audible by communication with an appropriate receiver. We must, however, do no more than indicate the existence of an analogy, the full development of which, though eminently interesting, would lead us too far from our present purpose.

§ 215. A ray of light then consists, according to the first hypothesis, of a line of particles projected from the luminous body, and impinging upon the eye; according to the second, of a series of undulations excited by the luminous body which reach the eye, and produce the sensation of light by corresponding vibrations of the optic nerve.

An assemblage of a number of such rays, proceeding together in the same direction, is called a *pencil* of rays.

Having premised thus much upon the hypothetical views of the nature of light, we will proceed to examine the phenomena, and the laws by which they are governed, with as little regard to hypothesis as possible; and we shall speak of a ray of light as of a radiant force, without reference to its nature, and the mode of its propagation.

§ 216. Light requires time for its propagation; but the rapidity with which it travels is so great as to be absolutely insensible in such distances as occur on the surface of the earth. It is only when we direct our observations to the celestial bodies, whose distances from us are commensurate with its velocity, that we can appreciate the fact. Astronomy has proved, by the most unexceptionable calculations, that its progress is at the rate of 195,000 miles in a second of time—a velocity which transcends all comprehension; and it is only by reflection, and a comparison with more familiar phenomena, that we can form some conception of it.

"A cannon-ball would require seventeen years at least to reach the sun, supposing its velocity to continue uniform from the moment of its discharge; yet light travels over the same space in seven minutes and a half. The swiftest bird, at its utmost speed, would require nearly three weeks to make the tour of the earth; light performs the same distance in much less time than is required for a single stroke of its wing *."

§ 217. The first relation of light to ponderable matter, which we shall notice, is, that most bodies possess the property of intercepting it in its progress, whilst a few allow it to traverse their substance. Hence the distinction of bodies into opaque and transparent or diaphanous. The light of the sun, or of a lamp, freely reaches us in straight lines, through a plate of glass, but is wholly excluded from our eye by the interposition of a plate of metal.

An opaque screen interposed between a luminous body and a sheet of paper, or other object, casts what is called a *shadow* upon such object, and the *shadow* is similar in figure to the section of the body which produces it; and hence we learn that the rays of light are transmitted in straight lines. The luminous rays are cut off by the body of the screen, and being prevented from falling upon the object behind the surface, exactly coincident with its boundary, remain in a state of darkness; but they continue their course beyond its edge, and illuminate the surrounding space.

§ 218. The law of the decrease in proportion to the squares of the distances, may be experimentally proved by means of the shadow of an object; for a board of a foot square, at a certain distance from a light, just shadows a board of two feet square at double the distance, and the latter has four times as much surface as the former; *i. e.*, the light which is concentrated upon the first board would be diffused over four times the space, if suffered to fall upon the second. (See fig. 1.)

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* HERSCHEL'S *Discourse*.

An accurate photometer, or measure of light, is still a desideratum of science. A very simple method of comparing two sources of illumination, was suggested by Count Rumford. They are so arranged as that each may cast a shadow of some object, as a stick, upon a plain white surface; the eye can then form a tolerable judgment of the relative darkness of these shadows. The brighter light, which casts the deepest shadow, is then to be removed, or the weaker to be approached, till the two are equalized, and the distance of the two lights from the object which intercept their rays being measured, the relative intensity of the lights will be as the squares of the distances. In this case the shadow of one light is illuminated solely by the rays of the other, while the surrounding space is illuminated by the rays of both; when the shadows, therefore, are equal, the lights are equal. The eye, however, is not much more to be depended upon for an estimate of light than the hand is for the weight of an object presented to it, particularly when any difference of colour may tend to perplex the judgment.

§ 219. When a pencil of light traverses space, or a perfectly homogeneous medium, its course is rectilinear, and its velocity uniform; but when it encounters an obstacle or a different medium, it undergoes certain modifications, of the nature of which we must endeavour to form some distinct notions.

It separates itself into several portions which pursue different courses, and are otherwise differently modified. One of these portions is *regularly reflected* or turned aside, and after reflexion pursues a course wholly exterior to the obstacle or new medium; a second portion penetrates the medium, and is more or less *refracted* or bent out of its original direction; a third portion is *absorbed* or lost; and a fourth portion is repelled from the surface, and *radiates* itself in all directions.

§ 220. The primary law of reflection is, that the incident and reflected rays, which are always in the same plane, form equal angles with a perpendicular to the surface at the point of incidence. It is generally thus enunciated,—the angle of reflection is equal to the angle of incidence (50). This is the same law which governs the collision of matter moving under the influence of mechanical force; whether that motion be of a solid, direct in space, or of a liquid propagating by waves.

If we admit a small sunbeam into a darkened chamber, and receive it on a plane polished surface of glass or metal, we may easily convince ourselves of the fact by the measurement of the angles. Moreover, to see the image of any object by reflection, it is necessary to place the eye in a situation to receive the rays which proceed from the object at the same angle at which they originally strike the observer.

The greater the angle of incidence, the more light is reflected from all substances, except the metals which reflect the greatest quantity of light at small angles. Even the rough surface of a plaister of Paris cast, or a sheet of hot-pressed writing paper, will afford a very perfect image of an object at a very large angle.

§ 221. All known substances, not excepting air, the most diaphanous of all, reflect some portion of light, and it is calculated that a person plunged 150 feet in the clearest sea, would find the light of the sun no more than the light of the moon; and if we look at a luminous object through a transparent piece of glass, we shall find that the object becomes dim in exact proportion to its thickness, so that there is no such thing in nature as perfect transparency. On the other hand, there is reason to suppose that no body possesses the property of perfect reflection; for light penetrates in an inappreciable quantity into the surface of all bodies, and even into gold itself, as it is easy to be assured of, by holding a piece of leaf gold between the eye and any strong light, when it will be found to be permeable to bluish rays.

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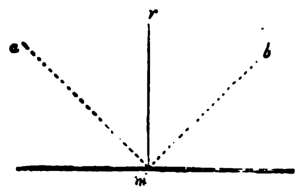
(50) Let *m* be a reflecting surface, and *r* a ray of light impinging upon it, in a perpendicular direction from *r* to *m*, it will then be reflected in the same direction, and return from *m* to *r*. If the ray of light fall upon *m*, in the direction *a m*, it will be reflected from *m* to *b*; the angle of reflection, *r m b*, measured from the perpendicular, *r m*, being equal to the angle of incidence, *r m a*, measured from the same perpendicular.



§ 222. Light may be so reflected from regular curved concave surfaces, that all the rays may converge to one point or focus. In this case, the direction of each reflected ray is the same as if it had taken place from a plane surface, tangent to the curve at the point of incidence (51).

§ 223. When a ray of light is admitted into a darkened apartment, it may be almost wholly turned aside by reflection from a metallic mirror, in any direction according to the angle at which the mirror is presented to it. If it then be made to fall upon any object, it will affect that object as the original ray; one part will be absorbed or extinguished, another reflected, and a third will be irregularly repelled or scattered: it will assume a state of *secondary radiation*. It is this portion which renders an object visible in all directions. This scattered light falling upon other bodies is again reflected and dispersed from them, and makes all of them also visible, although in a less degree because of the partial absorption which is constantly taking place, and the whole apartment is lighted. No such general lighting is produced by regular reflexion from the mirror, and the effect depends upon the nature of the body on which the rays fall. If it be upon a sheet of white paper which absorbs but little, the apartment will be well lighted, but if upon black velvet which absorbs nearly the whole, the apartment will remain dark.

This property is of the utmost importance to vision; it is possessed in various degrees by all bodies on the earth, and very remarkably by the atmosphere which surrounds it. By these means the light derived directly from the sun is diffused, and that milder radiance maintained, which is so agreeable to the eye, and which renders objects visible when the sun's direct rays do not fall upon them. But for this, indeed, all bodies shaded from the sun would be perfectly dark or black, that is, totally invisible; and without an atmosphere, the sun would appear a blazing orb in a black sky. On lofty mountains, when half the atmosphere is below the level of the observer, it is well known that the sun's rays are

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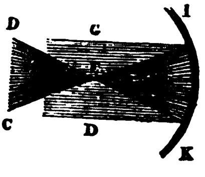
(51) Let I K represent the polished concave surface of a segment of a sphere; the pencil of parallel rays, C D, will be reflected from it, according to the law, so as to meet at the focus F, where they will also cross one another, and pass on in the same direction to D C.



painfully intense, and the sky is of the darkest hue, almost approaching to black.

§ 224. When a pencil of light falls on the surface of any transparent uncrystallized medium, as water, a portion of it is reflected, and another portion, which serves to make the surface visible, is scattered in all directions; the remainder penetrates the medium and pursues its course within it. If it enters it perpendicularly, it passes through in a straight line; but if at an angle, it is bent from its course, and is said to be *refracted*. In the reflection of light, the law, as far as regards the direction of the reflected ray, is the same for all reflecting substances: in refraction it is otherwise, and each different medium has its own peculiar action on light; some turning a ray incident at a given angle, more out of its course than others (52).

The degree of bending, or refraction of light in traversing a transparent medium, is ascertained by comparing the obliquity of its approach to the surface, with the obliquity of its departure after passing, and the ratio of these two angles when light passes from

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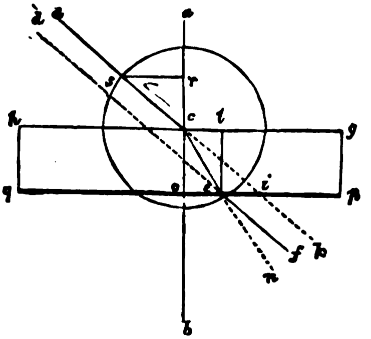
(52) If in this diagram, we suppose a ray of light shot from *a* to *c*, to penetrate the surface of a piece of glass, *g h*, it would reach directly across to *b*; but if the ray fall obliquely, as from *d* to *c*, then instead of continuing its course to *i* and *k*, it will at the moment of its entrance be bent downwards into the path *c e*, nearer to a line, *c o*, called the perpendicular to the surface at the point of entrance; and then moving straightly while in the substance of the glass, it will, when it passes out again at *e*, in the opposite surface, be bent just as much as at first in the contrary direction, or away from a similar perpendicular at the surface *i e*, into the line *e f*, instead of the line *e n*. A ray, therefore, passing obliquely through a transparent body of parallel surfaces, has its course shifted a little on one side of the original course, but still proceeds in the same direction, or in a line parallel to the first. An eye, therefore, looking at an object, *d*, obliquely through a piece of glass, *g h p q*, with parallel surfaces, would see it in the direction *f d'*, instead of the direction *f d*, and to the left of its real position.



a vacuum into a given substance, is called the index of refraction (53).

When light passes obliquely from air into water, the refraction or bending is such, that the line measuring the obliquity before the refraction, or the sine of the angle of incidence, is always longer than the line measuring it after refraction, or the sine of the angle of refraction, by nearly one-third of the latter: and the refractive power of water is therefore signified by the index 1⅓ or 1.33 : as in like manner, the greater refractive power of common glass has the index 1½: that of the diamond, 2½, and so on. Whatever relation holds between a ray and the refraction in any one case, the same holds good in all cases. If, for instance, the obliquity measured by its sine be 40, and the refraction be half, or 20, then in the same substance, an obliquity of ten will occasion a refraction of five, &c.

§ 225. Generally speaking, the refractive power of substances is in some degree proportioned to their densities: water, for instance, acts more powerfully than air, and has its power increased by solution of salt. Glass, again, is superior to either; but Sir I. Newton observed, that inflammable substances had greater refractive powers than others, and he in consequence foretold, what chemistry has since so remarkably verified, that the diamond and water would be found to contain inflammable principles.

Hydrogen, sulphur, phosphorus, wax, turpentine, camphor, and oils, are distinguished by a refractive power, many times greater in respect to their densities than most other substances. Chromate of lead, on the other hand, which is not combustible, possesses the power in an extraordinary degree.

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(53) For the purpose of determining the index of refraction, a line is supposed to be drawn perpendicularly through the surface, at the point of incidence, as in the last figure, *a b*, drawn through *c*, and the relative positions of the ray to this line are easily ascertained. Thus, if we strike a circle from the centre *c*, with the radius *c e*, in the plane of the ray *d c e*, the line *r s*, drawn from its point of intersection with the ray before incidence, to the perpendicular, will be a measure of the original obliquity, or angular distance of the ray, and is called the *sine of the angle of incidence*; and another line, *o e*, drawn from a corresponding point of the perpendicular to the ray after passing, is a measure of the obliquity after refraction, and is called *the sine of the angle of refraction;* by comparing these two lines, the amount of refraction is ascertained.

In the following Table is set down the refractive powers of the principal gases and vapours, compared with air:—

TABLE XXVI. *Refractive Power of Gases and Vapours.*

Barometer 30.

Air	1000	Chlorine	2.623
Oxygen	0.861	Alcohol vapour	2.220
Nitrogen	1.034	Ether vapour	5.280
Hydrogen	6.614	Sulpt. of carbon vapour	5.179
Ammonia	2.168	Cyanogen	2.832
Carbonic acid	1.004	Hydro-cyanic acid	1.531
Carbonic hydrogen	2.092	Carbonic oxide	1.157
Muriatic acid	1.196	Sulphuretted Hydrogen	2.187

The following Table registers the refractive power of some remarkable liquids and solids:—

TABLE XXVII. *Refractive Power of Liquids and Solids.*

Sulphuret of carbon	1.678	Chromate of lead	2.974
Tolu balsam	1.628	Diamond	2.439
Castor oil	1.490	Phosphorus	2.224
Almond oil	1.483	Calcareous spar	1.654
Spirits of turpentine	1.475	Quartz	1.548
Sulphuric acid	1.434	Resin	1.559
Alcohol	1.372	Rock-salt	1.557
Ether	1.358	Ice	1.308
Water	1.335	Tabasheer	1.111

§ 226. Many familiar phenomena might be sufficient to convince an attentive observer of this action of transparent substances upon light. Thus, when a stick is immersed obliquely in water, it appears bent at the point of immersion; and if an object, such as a piece of coin, be placed at the bottom of a basin, and the experimenter place himself so, that the side of the vessel may just conceal it, upon pouring water into it, it will become visible.

§ 227. The direction of the refracted ray depends upon the relative position of the surface of the transparent body, not only at its point of entrance, but also at its exit; and thus by variously modifying the surfaces of refractive media, the rays of light transmitted may be diverted almost at pleasure. By refraction at convex surfaces, for instance, they may be made to converge to a focus, and all their power condensed at one particular point; the refraction taking place as if each ray fell upon a plane surface, tangent to the curve at the point of incidence (54).

By a proper adjustment of surfaces, the original deviation of a ray entering a piece of glass may be doubled at its emergence, and some very curious effects produced. The phenomena may be best observed by means of a triangular prism of glass, or other refracting substance. The light which falls upon one of the faces is refracted at the first surface, and also at the second surface; but the second refraction does not bring the ray into a direction parallel with the incident ray, as is the case when the surfaces of the glass are parallel; but they are permanently bent into another direction (55).

§ 228. The most extraordinary fact connected with the refraction of light is, that a pure ray of white light from the sun,

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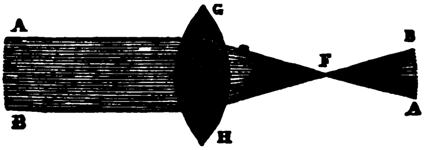
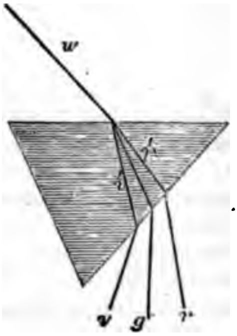
(54) G H, in the annexed figure, represents a lens of glass, the opposite convex surfaces of which are segments of similar spheres. The pencil of parallel rays, A B, in traversing its substance, are refracted at both surfaces; and, according to the law, upon their emergence from the glass, are so directed as to meet at the forces F, and crossing one another, pass on to B A.



(55) A ray of light, *w*, is here represented, impinging obliquely on the upper surface of the prism; it is there refracted out of its original direction towards a perpendicular to the surface. On emerging from the second surface it is further refracted into the direction, *g*, away from the perpendicular to that surface. It is also separated into different portions, of which *vr* are the extremes.

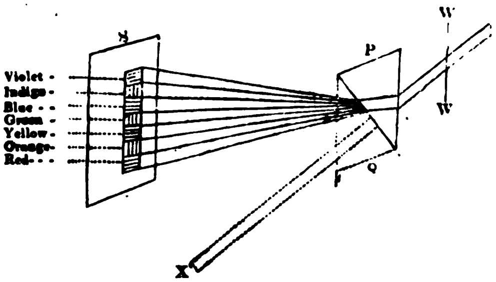


admitted into a darkened room, through such a prism, instead of being refracted altogether, and appearing still as a white ray, is divided into several rays of different vivid colours. It is thus said to be analyzed or decomposed into its elementary rays. Seven principal colours may be distinguished, viz., red, orange, yellow, green, blue, indigo, and violet; and it is owing to the unequal refrangibility of the rays which produce them that their separation is effected (56). The relation of the sine of the angle of refraction to the sine of the angle of incidence differs in each.

TABLE XXVIII. *Of the Refrangibility of the Rays of the Spectrum.*

	WATER.	FLINT GLASS.
	Index of Refraction.	Index of Refraction.
Red . .	1.3310	1.6277
Orange .	1.3317	1.6297
Yellow .	1.3336	1.6350
Green . .	1.3358	1.6420
Blue . .	1.3378	1.6483
Indigo. .	1.3413	1.6603
Violet. .	1.3442	1.6711

(56) In the annexed diagram R X represents a ray of light passing into a dark chamber through a small hole in the window-shutter, W W.



When a prism, P, with one of its angles downwards, is interposed in its passage, the ray, after suffering two refractions, is bent upwards towards S; and when received upon a white screen, placed at a considerable distance behind the prism, forms an oblong image, coloured with the most vivid tints named in the margin. When a similar prism, represented by the dotted triangle, Q, is placed before the first, in the reverse position, the opposite actions of the two correct each other, all colour disappears, and the effect is the same as would result from the interposition of a piece of thick glass, whose opposite sides are parallel.

§ 229. Thus the red ray is the least bent, and the violet the most. This unequal refrangibility is not an accidental circumstance, but is a property inherent in their nature, and which each retains after being subjected to several refractions; and no action of refraction or reflection is capable of effecting their further decomposition. If they be again collected, as they may be either by refraction through the convex surface of a lens, or by reflection from the concave surface of a mirror, they will reproduce white light at the respective foci.

The space illuminated and coloured by a pencil of rays from the sun thus analyzed, is called the *solar spectrum*.

It is to Newton we are indebted for these beautiful experiments, and for a theory of colours founded upon them.

§ 230. The composition of white light from the seven prismatic colours may be roughly proved by painting them upon the face of a wheel, and causing it to rotate rapidly. Owing to the permanence of the impression upon the retina of the eye (§ 212) they thus become blended together, and a sort of greyish white is the result. The white is imperfect, because the colours employed cannot possibly be obtained of the proper tints, or laid on in exact proportions.

§ 231. This analysis of white light, however, is not wholly dependent upon the refractive power of a transparent medium, but upon what may be called its *dispersive power;* and different bodies possess very different powers of dispersing or separating the coloured rays of light. If, for example, we make a hollow prism of plates of glass, and fill it with oil of cassia, we shall find that the spectrum which it produces will be two or three times longer than that of a glass prism. Different substances not only exhibit the difference of dispersive power generally upon all the rays of light, but are found to act unequally upon the different rays: thus, if we compare the spectra produced by oil of cassia and sulphuric acid, we shall find that the least refrangible colours, red, orange, and yellow, will occupy less space in the former than in the latter; while the most refrangible colours, blue, indigo, and violet, will occupy larger spaces, or be more expanded.

§ 232. The dispersive powers of dense flint-glass, and of the lighter crown-glass, differ very considerably; and it is possible so to adjust two prisms of these substances together that their dispersive powers may correct one another; and yet that a considerable deviation or refraction of the light which penetrates them may remain. It is upon this principle that Dollond first effected the important object of correcting the colours which surround the image of objects in a common telescope. Every simple lens acts, in some measure, upon light as a prism, not only causing the rays to converge to a focus, but separating them by its dispersive power; by the proper adjustment of different kinds of glass, a compound lens may be constructed in which the colour is greatly corrected, and the rays are still made to converge in the requisite degree.

§ 233. The solar spectrum, however, in its utmost purity is not, as it appears to common observation to be, an uninterrupted line of light, red at one end and violet at the other, and shading away, through every intermediate tint from one to the other; but is interrupted by intervals absolutely dark; and in those parts where it is luminous, the intensity of the light varies. When viewed in the most advantageous way, and with proper precautions, it presents the appearance of a striped riband, being crossed in the direction of its breadth by an infinite multitude of dark, and by some totally black bands, distributed irregularly throughout its whole extent. The bands are constantly in the same parts of the spectrum, and preserve the same order and relations to one another,—the same proportional breadth and degree of obscurity, whenever and however examined, provided solar light be used. By solar light must be understood not only the direct rays of the sun, but the reflected and scattered light from the same source, as the light of the clouds or sky, of the moon or planets (57). Though similar bands are observed in the spectra from other lights, as that of the fixed stars or of artificial lights, yet they are differently disposed, and the spectrum of

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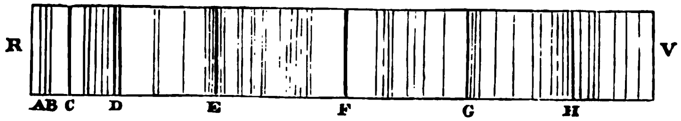
(57) The principal lines in the solar spectrum are here represented. R is the red extremity, and V the violet; C is a broad black line beyond the middle of the red. At D is a strong double line in the orange, the two being separated by a bright one; E is the middle one of a number in the green. At F there is a strong black line in the blue. G is in the indigo, and H is the most remarkable one in the violet. Between these, others are situated so thickly that the number of the whole amounts to about 590.



each has a system of bands peculiar to itself. This phenomenon has been ascribed to the action of the solar atmosphere, which may have the property of absorbing particular portions of the rays of light. A similar specific action has been found in different gases and vapours, to which we shall again refer when examining the properties of heterogeneous kinds of matter.

In the spectra from artificial lights, some of the colours are sometimes wanting.

§ 234. The decomposition of light may also be effected by absorption: thus, rays of homogeneous colours may be obtained by transmission through glass stained with certain metallic oxides:—

Homogeneous red . . .	Oxide of copper.
„ blue . . .	„ cobalt.

But more ordinarily the colours of natural objects are compounded of several rays, which are left after the absorption of others.

§ 235. Thin plates or scales of different substances, or substances divided by fine regular lines, or consisting of minute fibres, have also the property of decomposing light which falls upon them; but the series of phenomena which they present are totally different, and depend upon different principles. The simplest case, perhaps, of this curious property occurs, if we allow a small beam of divergent light to enter into a dark room by a hole not more than 1-40th part of an inch diameter, or better still, through a small convex lens, and place a thin rod of any kind of matter, such as a pin, in its course; if we then examine its shadow, we shall find that on both sides of it there are fringes of coloured light, the colours being as follows, looking from the shadow:—

First fringe . . .	Violet, indigo, pale blue, green, yellow, red.
Second fringe . . .	Blue, yellow, red.
Third fringe . . .	Pale blue, pale yellow, red.

§ 236. If instead of white light, any of the homogeneous rays of the spectrum be observed in the same way, the fringes will be of the same colour, and their intervals black.

If we now examine the shadow itself, we shall find that it also is divided by parallel fringes, which vary in number and in breadth, according to the distance of the body from the shadow that is examined.

Now these phenomena must depend upon light *bent* somehow or other into and towards the shadow, and the name of ***inflection*** has been employed to distinguish them. The name of ***diffraction*** has also been applied to them.

If a screen be placed on one side of the inflecting body, and a little behind it, so as to cut off the access of light to that side, the light will pass by on the other side, but all the fringes in the shadow will disappear; proving that the fringes in the shadow are occasioned by the *interference* of the rays bent into the shadow on one side of the body, with the rays bent into the shadow on the other (58).

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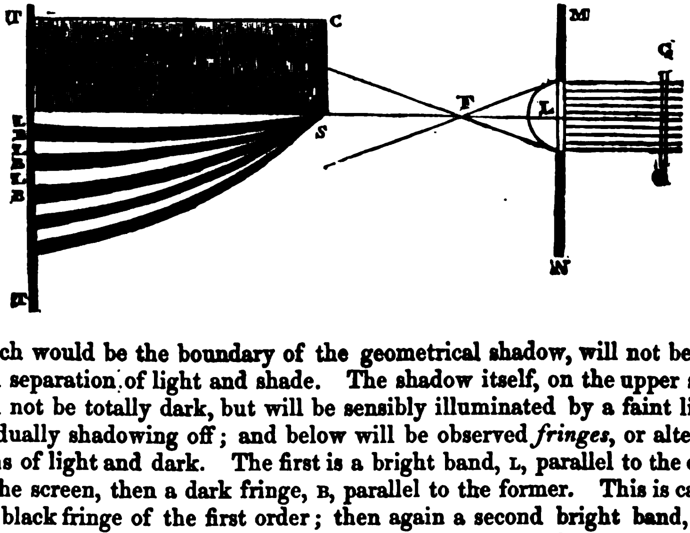
(58) Let a pencil of rays pass through a glass, G G, of homogeneous colour, and fall upon a lens, L, of short focus, fixed in a diaphragm, M N. Place at a little distance from the focus a screen, C S, with a thin fine edge, and receive its shadow on a white screen, T T. The line, F S L, which would be the boundary of the geometrical shadow, will not be the real separation of light and shade. The shadow itself, on the upper side, will not be totally dark, but will be sensibly illuminated by a faint light, gradually shadowing off; and below will be observed *fringes*, or alternations of light and dark. The first is a bright band, L, parallel to the edge of the screen, then a dark fringe, B, parallel to the former. This is called the black fringe of the first order; then again a second bright band, and then a black one, which is called the black fringe of the second order; and so on successively till black fringes may be observed, under favourable circumstances, of the sixth and seventh orders. The bright bands become less and less brilliant, till they are confounded with the light which passes by the edge of the screen.



All the colours of the spectrum produce this effect, with only this difference, that in passing from the red to the violet they become narrower and narrower. It is for this reason that white light does not give black and white fringes, but fringes of different colours arising from the mixture of the prismatic colours in different proportions.

§ 237. "The law of this interference may be thus explained. Let us suppose two minute pencils of light, radiating from two points close to one another, to fall upon the same spot of a piece of paper, in which case they may be said to interfere with one another, (for if the paper were removed, they would cross one another at that point). Then if the lengths of their paths (or the distances between the paper and the two radiant points,) are the same, they will form a bright spot or fringe of light, having an intensity greater than that which would have been produced by either portion alone. Now it is found that when there is a certain difference between the lengths of their paths, a bright fringe is produced, exactly similar to what is produced when their lengths are equal. If we represent this difference by the letter *d*, then similar bright spots or fringes would be

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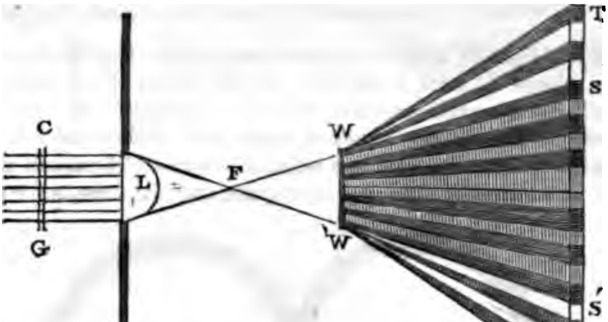
The different fringes have their origin in the edge of the screen; and by tracing them at different distances of some yards from this origin, it is found that they propagate themselves in hyperbolic curves, as represented upon an exaggerated scale in the preceding diagram.

The concentration of the light by a lens is not necessary to the phenomena.



Supposing the arrangement to be as before, only that at a little distance from the focus a hair, or fine wire, W W, be placed in the course of the ray[illegible] geometric shadow would reach to S S, on the screen, T T. B[illegible] this, on each side, S T, S' T' fringes may be observed, analogous to [illegible] arising from the edge of the screen. These are called *exterior fringes*.

But in addition to these, *interior fringes* may be observed, occupying the whole width of the shadow. As before, they are larger in red than in violet light, &c., and consequently with white light present colours of various tints.

produced when the difference in the lengths of the paths are 2 *d*, 3 *d*, 4 *d*, 5 *d*, &c.; but, what is very remarkable, it is clearly proved, that if the pencils of light interfere at intermediate points, or at ½ *d*, 1½ *d*, 2½ *d*, 3½ *d*, then, instead of adding to one another's intensity, the two pencils of light destroy one another, and produce a black spot or fringe." (59.) The distances at which these interferences take place are different for the different coloured rays of the spectrum; and hence, although with homogeneous light, the fringes are only of the colour of the inflected ray alternating with black, when compound light is employed, they consist of various mixtures of the rays in a definite order.

§ 238. In giving even the most superficial account of these interesting phenomena, it is almost impossible to avoid alluding to the two rival theories of light, for the purpose of remarking that the undulatory hypothesis explains them in the most satisfactory manner, and taking either the analogy of liquid undulations, or the musical vibrations of two strings, we shall find similar interferences occurring. When a system of waves on water interfere with one another at certain intervals, the force of one is added to the force of the other, and the height of the waves is doubled; but when they

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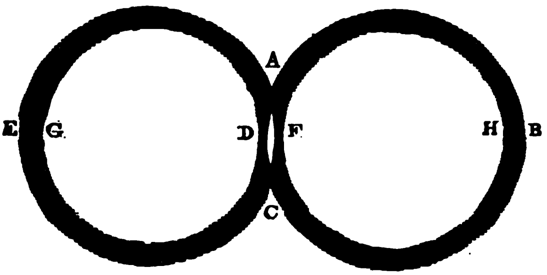
(59) If light be allowed to enter into a dark chamber by two small pinholes, placed at such a distance that the cones of rays only intersect one another at a certain distance, and it be received upon a white screen, the shaded circles in the annexed figure will define the limits of the illuminated spaces; the common segment AFCD will be much more illuminated in its interior than any other part, and the arcs, ADC and AFC,



will be of remarkable blackness, although they receive more light than the rest of the circumferences of which they form a part.

If one of the holes be closed, the points in ADC or AFC, become more brilliant, although deprived of the additional light from the second hole. Light added to light thus produces darkness, and an obscure space becomes lighted by the abstraction of light.

interfere at intermediate intervals, the rise of one corresponds with the fall of the other, and both are obliterated. Or that kind of alternate cessation and increase of sound which is produced by two musical notes nearly in unison, and which is known by the name of *beats*, presents a striking analogy with the alternate luminous and black fringes arising from the interference of light.

§ 239. Thin plates of different substances produce analogous phenomena of colour by the interference of the rays, reflected from the second surface of the plate, with the light reflected from the first surface. This may be very well exemplified by thin sheets of mica, which may be procured of any degree of tenuity, by splitting the edge of the plate, and then rending it asunder with a sharp pull. The colours depend upon the thickness of the plate, and are never the simple colours of the prism. Whatever tints are thus produced by reflected light, the complementary tints, or those colours which are required to constitute white light by mixture with them, may be found in the light which is refracted through them. The same effects are produced in a very beautiful manner in soap-bubbles, which, as they grow thinner by evaporation, exhibit a series of the most splendid colours. A drop of oil thrown upon a surface of water, or glass blown very thin, produces similar results.

The iridescent colours which are seen upon the surface of *mother-of-pearl* are referrible to fine parallel lines formed by its texture; and are produced, in a minor degree, even by the surface of sealing-wax, upon which their impression has been taken. The splendid and variable colours of the plumage of many birds is also dependent upon their fibrous arrangement; while in the gorgeous colours of shells and fish we see the effects of a thin laminated structure.

§ 240. But the most beautiful illustration of the subject is in the coloured rings of Newton, the laws of which were illustrated by that unrivalled philosopher.

He placed two convex lenses of long focal lengths above one another, so as to touch at their summits. They were kept together by three pairs of screws at equal distances from each other, so as to produce regular pressure at the point of contact. A regular system of circular rings appeared round this point, having a black spot in the centre; each spectrum, or order of colours, consisting of fewer colours as they receded from the centre. The order of the colours of the thin plate of air included between the glasses, is given in the following table, both for reflected and for transmitted light:—

TABLE XXIX. *Colours of Newton's Rings.*

	Reflected Light.	Transmitted.
FIRST SPECTRUM . .	black. blue. white. yellow. orange. red.	white. yellowish red. black. violet. — blue.
SECOND SPECTRUM . .	indigo. blue. green. yellow. orange. red. scarlet.	white. yellow. red. violet. — blue. —
THIRD SPECTRUM . .	purple. indigo. blue. green. yellow. red.	green. — yellow. red. — bluish green.
FOURTH SPECTRUM . .	bluish green. yellowish green. red.	red. — bluish green.
FIFTH SPECTRUM . .	blue. red.	red. —
SIXTH SPECTRUM . .	blue. red.	— —
SEVENTH SPECTRUM .	greenish blue. white.	— —

Sir Isaac Newton ascertained in this way, by direct measurement, that air at and below a thickness of half a millionth of an inch ceases to reflect light, and at and above a thickness of seventy-two millionths of an inch it reflects all the rays of the spectrum. Between these two limits it reflects the various orders of colours set down in the table.

Water at and below a thickness of three-eighths of a millionth of an inch ceases to reflect light; at and above fifty-eight millionths it reflects white.

And glass transmits all light at a thickness of one-third of a millionth of an inch, and reflects all at and above fifty-millionths of an inch (60).

§ 241. The law of ordinary refraction, which we have hitherto considered, is very far from general, and it only obtains where the refracting medium belongs to one or other of the following classes:—

1. Gases or vapours.
2. Liquids.
3. Bodies solidified from the liquid state so suddenly, as not to admit of regular crystalline arrangement, such as glass, jelly, gums, resins, &c.
4. Crystallized bodies of that class which may be supposed to be constructed of spherical particles, such as the regular cube, octohedron, &c.

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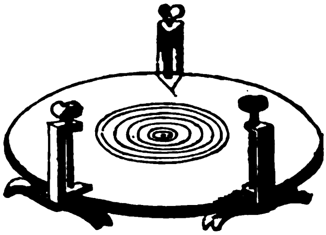
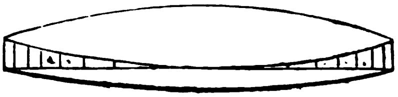
(60) The arrangement of the lenses is here shown, with the coloured concentric rings arising from the thin film of air enclosed between them:



and in the annexed figure they are exhibited in section; the proportion of the curvatures being much exaggerated, in order to show the gradual increase in the thickness of the film.



These solid bodies even cease to belong to this class when they are forcibly compressed or dilated either by mechanical force or the unequal action of heat. All other bodies, such as salts, crystallized minerals, all animal and vegetable bodies in which there is a tendency to regularity of structure,—as horn, quill, mother-of-pearl, &c.,—act upon light in its passage through them in a very different manner. They divide the refracted portion into *two distinct pencils*, each of which pursues a rectilinear course within the medium, according to its own peculiar law.

§ 242. The best exemplification of this mode of refraction is to be found in a substance called Iceland spar. It is perfectly transparent and colourless, and susceptible of a high polish. It may be cleaved or broken into solids of a rhombohedral form, and the natural faces are generally even and perfectly polished (§ 112).

If we take a rhombohedron of this substance, and look at a small illuminated object through it, or a line of light passing through a slit in an opaque plate, or a black line upon a sheet of paper, in certain positions, two images of the object will appear; and upon turning the rhombohedron round in its own plane, so as to make a complete revolution, the two images will assume a regular movement with regard to each other, so that one will fall upon the other, or coincide with it twice in the revolution; and it will be easy to ascertain that these coincidences take place in two positions of the spar, which are directly opposite to each other. The maximum separation occurs at the two intermediate points of the revolution, and the distance is proportioned to the thickness of the rhombohedron (61).

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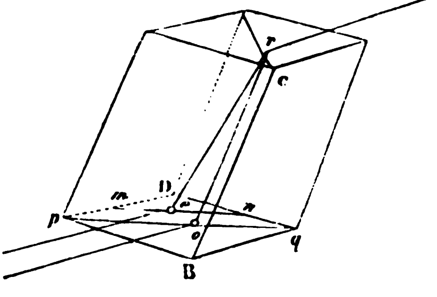
(61) If we place the rhombohedron, as in the annexed figure, above a sharp line, the line will appear doubled, as *m n*, *p q*; or a dot will be doubled, as *e o*. If we cause a pencil of light, R *r*, to fall upon



Hence it appears that a ray of light, in passing through Iceland spar, is split into two by some force residing in the crystal.

§ 243. Now, the line which joins the obtuse angles of such a rhombohedron is designated as the axis of the crystal, (§ 124,) and it is also the optic axis of the mineral. Whenever a ray of light passes along this axis, or the principal section, or plane, of the crystal in which it is contained, (and which may be conceived to contain an infinite number of the similar axes of the primitive molecules of which it is composed,) it passes whole and undivided; and if two artificial planes be ground parallel to one another, and perpendicular to the axis, an object will appear single when viewed perpendicularly through them. In all other directions the ray will be divided into two, one of which follows (nearly) the laws of ordinary refraction, and may be denominated the *ordinary* ray; the other varies from those laws, inasmuch as in general its plane of refraction does not coincide with the plane of incidence, and the sines of incidence and refraction cease to have a constant relation to each other: it is distinguished as the *extraordinary* ray. The sines of incidence and refraction, however, of the extraordinary ray, are always constant in the same substance at the point of greatest deviation, which happens when the ray passes along a plane at right angles to the axis of the crystal; and in certain substances, the index of refraction of the extraordinary ray is sometimes greater, and sometimes less, than the index of refraction of the ordinary ray. Hence, crystals have been distinguished as repulsive and attractive, or negative and positive crystals.

There are crystals of other substances, again, which present two optic axes, along which a ray of light can penetrate without being divided: but the position of these cannot conveniently be determined with regard to the crystallographical axis.

§ 244. If the rays of light which have been separated by passing through a crystal of Iceland spar, be made to pass through

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the surface of the crystal, it will be separated into two rays, *r o*, *r e*, which will respectively emerge at *o* and *e*, in the directions *o o′*, *e e′*, parallel to R *r*. The same phenomena will occur by making the ray R *r* fall at the same incidence, and in the same direction relatively to the summit A, upon any point of the faces. The plane A C B D is called the principal section of the crystal, and the axis, or the line which may be drawn from the solid angle A to the angle B, is contained in it.

another crystal placed similarly to the first, there will be no further subdivision of the light; the two images will be merely separated to a greater distance from the increased thickness through which the rays pass. If, again, the two crystals be so placed that the principal sections are at right angles to each other, there will be still but two images; but the ray ordinarily refracted in the first, will become extraordinary in the second, and the extraordinary ray will become the ordinary. But at all intermediate positions of the two crystals there will be a subdivision of each ray, and consequently four images. These four images will be of equal intensity when the principal sections of the two crystals are at an angle of 45° to each other; at all other angles one or other of the images diminishes in intensity as the principal sections approach to a perpendicular or parallel position.

Each ray emerging, then, from a crystal of Iceland spar, is only subject to a further division in particular positions of a second crystal; whereas natural light is always divided into two portions of equal intensity. Each ray has suffered a physical change; it is not acted upon by the force of the second crystal as natural light would be, but requires that the force be applied in a particular direction relatively to the modification it has received from the first crystal.

§ 245. This physical change has been called *polarization*, (a term derived from hypothetical considerations of the supposed arrangements of the poles of the molecules of light upon the theory of emission, but which must now be considered merely as a conventional term to express a class of phenomena). There are many crystallized minerals which, when cut into parallel plates, are sufficiently transparent to allow abundance of light to pass through them with perfect regularity, which, upon its emergence, is found to have acquired the peculiar modification here in question. One of the most remarkable of these is the *tourmaline*. If we take a well-polished plate of this mineral of moderate thickness, cut from a crystal of a brown colour in a direction parallel to the axis of the prism, a candle may be seen through it as through a plate of coloured glass; and no change will be observed upon turning it round. If another similar plate be interposed between the first plate and the eye, and turned slowly round in its own plane, the candle will appear and disappear alternately at every quarter revolution of the plate; passing through every gradation of brightness, from the maximum to a total, or nearly total, evanescence, and then increasing again by the same degrees as it diminished before. If we attend to the position of the second plate with respect to the first, we shall find that the maximum of illumination takes place when the axis of the second plate is parallel to that of the first.

§ 246. If we examine the two pencils of light after separation by a crystal of Iceland spar, by means of a plate of tourmaline, we shall readily perceive that the ordinary image (that which is not deviated from the axis of the crystal) acquires its greatest intensity when the axis of the tourmaline is perpendicular to the principal section of the rhombohedron, and that it becomes extinct in the opposite direction. When the axis of the tourmaline lies in the principal section itself, the extraordinary image (that which lies out of the axis and deviates from it) presents phenomena exactly the inverse of the former.

§ 247. The polarization of a ray of light may also be effected by reflexion. It takes place at a certain angle of incidence (which is therefore called the polarizing angle), which is different for different substances. When a ray of light is made to fall upon a polished glass surface, at an angle of 56° 45′, the angle of reflexion will, according to the general law, be equal to the angle of incidence; and if in this position it be viewed through a plate of tourmaline, it will exhibit the same series of phenomena as if it had been passed through another plate of the same substance. The light is extinguished when the axis of the tourmaline is parallel to the plane of reflexion.

If, instead of viewing the reflected ray through a tourmaline, we place another plate of glass so that the reflected ray may fall upon it at the same angle as upon the first, this second plate may be made to turn round its axis without varying the angle which it makes with the ray which falls upon it. When the two planes of reflexion are parallel to each other, the ray of light, or luminous object, will be reflected from the second glass, in the same manner as from the first; but if we turn the second glass round a quadrant of a circle, so as to make the reflecting planes perpendicular to one another, the whole of the ray will pass through the second glass, and none of it will be reflected. Let us turn the second glass round another quadrant, so as to make the reflecting planes again parallel, and the ray will be again wholly reflected. When the glass has been turned round three quadrants, the light will be again extinguished.

As both the pencils of light, into which a ray is divided by passing through a rhombohedron of Iceland spar are polarized, but in opposite directions, on viewing the reflexion of a lamp from glass, at the proper polarizing angle, through such a crystal, the two images will alternately appear and disappear as it is turned upon its axis.

§ 248. It may perhaps assist our comprehension of the connexion of these phenomena to illustrate them by a rough analogy: a ray of common light as it is emitted from a self-luminous body we may conceive to revolve upon an axis coincident with its own direction, as a cylindrical rod may be made to turn,—or, which comes to the same thing,—the reflecting or refracting surface may be made actually to revolve around the ray, as an axis, preserving the same relative position to it in all respects, and no change in the phenomena will be perceived.

But if, instead of employing such a ray of ordinary light, we subject to the same examination a ray which has been subjected to the action of certain material bodies, and has become polarized in the way which we have just examined, we find this perfect uniformity of result no longer to hold good. It is no longer indifferent in what plane, with respect to the ray itself, the reflecting or refracting surface is presented to it. It seems to have acquired sides, a right and left; a front and back; and to be no longer like the cylindrical stick, but like a four-sided one. If we imagine a surface to be made up of detached fibres, all lying in one direction, or of scales, or of laminæ, arranged parallel to one another, we should find no difficulty in thrusting the cylindrical stick through such an arrangement, in any direction; but a flat ruler would only penetrate it in one direction.

The two rays of light, polarized in opposite planes, after emerging from a rhombohedron of Iceland spar, may be represented by two such rulers presented to the bars of a grating, in opposite directions; while the thin edge of one passed freely between them, they would present an impassable barrier to the other, which would be presented to them crosswise. Supposing the grating to revolve upon its axis, on the completion of the first quadrant, the first would be arrested, and the second would pass; and so they would alternately pass and be stopped at each quadrant of the turn.

We find, however, in Professor Wheatstone's experiments, to which we have before referred, a much more refined and natural analogy to the phenomena of polarized light in sound. We have already seen that when a tuning-fork is connected with one extremity of a straight conducting-rod, the other end of which communicates with a sounding-board, on causing the fork to sound, the vibrations are powerfully transmitted. But on gradually bending the rod, the sound progressively decreases, and is scarcely perceptible when the angle becomes a right one. As the angle is made more acute the phenomena are produced in an inverted order; the intensity gradually increases as it before diminished, and when the two parts are nearly parallel, it becomes as powerful as in the rectilinear transmission. By multiplying the right angles in a rod, the transmission of the vibrations may be completely stopped.

To produce these phenomena, it is necessary that the axis of the oscillations of the tuning-fork should be perpendicular to the plane of the moveable angle, for if they be parallel with it, they will be still considerably transmitted. Professor Wheatstone placed a tuning-fork perpendicularly on the side of a rectilineal rod, the vibrations were therefore communicated at right angles; when the axis of the oscillations of the fork coincided with the rod, the intensity of the transmitted vibrations was at its maximum; in proportion as the axis deviated from parallelism, the intensity of the transmitted vibrations diminished; and, lastly, when it became perpendicular, the intensity was at its minimum. In the second quadrant the order of the phenomena was inverted, and a second maximum of intensity took place, when the axis of the oscillations had described a semi-circumference, and had again become parallel, but in an opposite direction. When the revolution was continued, the intensity of the transmitted vibrations was varied in a similar manner; it progressively diminished as the axis of the oscillations deviated from being parallel with the rod, became the least possible when it arrived at the perpendicular, and again augmented until it remained at its first maximum, which completed its entire revolution.

§ 249. This state of polarization once acquired by light, is retained by the ray in all its future course (provided it be not again modified by other bodies), for it matters not how great the distance between the substance operating the change and the substance by which it is afterwards analyzed, whether they be in contact or many inches, yards, or miles asunder, not the least variation can be perceived in the phenomena in question.

§ 250. Different substances polarize light by reflexion at different angles.

The angle for	Glass	is 56° 45′
„	Water	53° 11′
„	Rock crystal . . .	56° 58′
„	Iceland spar . .	58° 51′
„	Sulphur . . .	63° 45′
„	Diamond . . .	68° 1′

§ 251. Light may also be polarized by successive reflexion, from the different surfaces of several plates of transparent substances at other angles, as, for instance, from a pile of five or six glass plates: and the portion which in this case penetrates through the pile, is found to be exactly equal to the former, and also to be polarized, but in the opposite plane.

§ 252. But the most interesting, as well as the most splendid, of all the phenomena of polarized light, are the vivid and gorgeous colours which are developed by the action of crystallized plates, under certain conditions. If a ray of light, polarized in any of the ways which we have described, be made to traverse a thin plate of mica, or sulphate of lime, which is perfectly diaphanous and colourless to common light, and then analyzed by a plate of tourmaline in that particular position in which without the plate it would wholly disappear, the ray will appear, but coloured in the most splendid manner with different tints, dependent upon the thickness of the plate; the tint will also vary with different degrees of inclination of the plate, these, in fact, being equivalent to different thicknesses. There are, however, certain thicknesses dependent upon the nature of the crystallized plate, beyond which the phenomena are not produced.

If the analyzing plate be now turned upon its axis, the ray will exhibit at the first quadrant the complementary colour, or that colour which, if superimposed upon the first, would produce white light; but, upon continuing the rotation, it will re-appear at the position opposite to the first, with the original tint. It thus appears that the original polarized ray suffers a bifurcation—or *bipolarization*, by its passage through the crystallized plate, and that its plane of polarization is altered. This splitting of the polarized ray differs from that which takes place when the rays pass from a rhombohedron of Iceland spar into another with its axis at right angles to the first: for, in the latter case, all the rays are equally divided in the two pencils, and constitute white light, while in the former the colours of two halves of the spectrum are combined in the oppositely-polarized rays.

§ 253. These phenomena appear more striking when the analysis of the ray is made with Iceland spar, for then two images are seen together of complementary colours; and they are proved to be complementary by their producing white light at the point at which they coincide or overlap each other.

§ 254. When the original polarized ray is made, however, to pass along the optic axis of the crystallized plate, it exhibits none of these phenomena.

Another series of beautiful appearances present themselves when a ray of white polarized light is made to traverse perpendicularly a plate of any crystallized substance with a single axis. If it be then examined with a plate of tourmaline, a series of concentric rings will be perceived, of different most vivid colours. The phenomena will change their aspect with the position of the tourmaline. When the axis of the tourmaline is in the primitive plane of polarization the rings will be traversed by a beautiful black cross, extending its arms to a great distance. When the axis of the tourmaline is in the opposite direction, the black cross will be replaced by a white one, and in all respects the second image will be complementary to the first (62).

§ 255. Iceland spar (or calcareous spar) presents this phenomenon in great perfection, but all other crystallized bodies with

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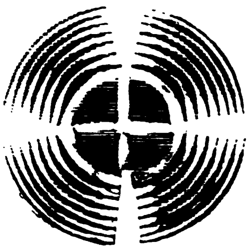
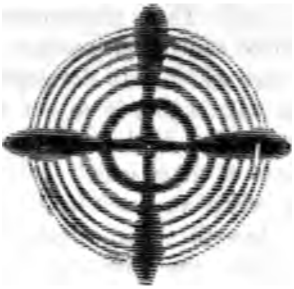
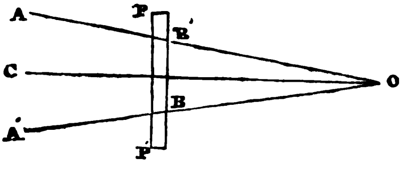
(62) These changes are represented in the annexed figures.







Suppose P P' to represent the plate of mineral, cut perpendicularly to its axis; the polarized rays form a species of luminous cone, O B B', of which the apex, O, is in the eye, and the base, B B', has a diameter variable with the distance, and of which the axis C O coincides with the axis of the crystal. The different rays of this cone experience very different effects; those which lie near the axis C O, traverse the plate without deviation, and are therefore subject to two refractions, ordinary and extraordinary; but these two refractions are always accomplished in the same plane, because every perpendicular section passing by the axis C O, is a *principal* section. Moreover, the different rays A O, A' O, equally distant from the axis, suffer very different modifications in their planes of polarization; and, from the interference of the rays, so oppositely polarized, present the succession of colours which we have described.

one axis, of double refraction, exhibit similar systems of rings. It is, however, very remarkable that some crystals exhibit this action in opposite directions. Thus, if we take a system of rings formed by ice or zircon, and combine it with a system of the same diameter formed by Iceland spar, the two systems will destroy one another; and hence it is concluded that the system of rings produced by these crystals are positive or opposite in character to the negative system of rings in calcareous spar.

§ 256. Crystals which have two axes of double refraction present double systems of rings when examined in the same way, and the changes produced in the combinations of the black and white crosses with the coloured rings, when the crystal and the tourmaline are turned upon their axis, are of the most interesting description, but are too complicated to find a place in the cursory glance which it consists with our present design to cast upon this beautiful department of natural philosophy (63).

§ 257. These phenomena are not only presented by regularly crystallized bodies, but mechanical pressure is capable of conferring a structure which will develope them. Thus the bending of a slip of glass will enable it to act upon polarized light at the part of greatest tension, in the same manner as a crystal of carbonate of lime.

Plates of glass which have been heated and suddenly cooled, present, when analyzed by a polarized ray which has been transmitted through them, rings and crosses and coloured tints which depend upon the form of the plate; a square plate of unannealed glass thus examined presents at its four angles small circular figures separated by a large black cross. These small circular figures also appear at the corners of any rectangle; but the cross is replaced by coloured bands parallel to the greater sides of the

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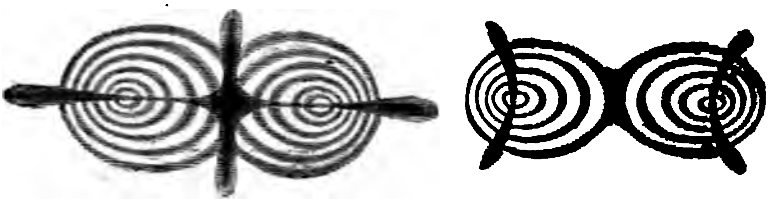
(63) These figures may convey an idea of the phenomena presented by a crystal of nitre, which belongs to the binaxial system, subjected to the action of polarized light, in opposite positions of the analyzing plate.



rectangle. A round plate exhibits concentric coloured rings, intersected by a large cross; if the circle be ground down to a square, the original disposition of the colours will return; or if the corners of the square be ground off, the circles will make their appearance (64).

In all these cases, upon turning the analyzing plate upon its axis, the colours change to the complementary colours at the opposite quadrants, and the black cross to the white.

§ 258. These effects are due to the forced state of compression in which the particles of the glass are held by the sudden cooling of the outer layer, and they entirely disappear when the glass is perfectly annealed. The direction of the force, and the consequent arrangement of the particles, is altered every time any portion of such a mass, even the slightest, is removed, and thus by grinding the different figures down to others, the tension is altered in certain directions, and their consequent action upon the polarized ray is also altered. If a square sheet of caoutchouc be stretched at its four corners, and one of them be then cut off, the manner in which it will retract itself from this point will explain, by a rough analogy, the mode in which the particles of unannealed glass are affected by the mechanical removal of any portion of their aggregate.

§ 259. There is one more class of these phenomena to which we must yet refer. If a ray of polarized light be passed through a plate of quartz, cut at right angles to its axis, upon examination it will not be found polarized in the same manner as in crystals with one axis, but the place of the black cross will be occupied by colours which fill up the first ring, and encroach upon the rest. These colours vary with the thickness of the plate, but they suffer no change by turning the plate round upon its axis. Suppose the colour in the centre of the rings to be red; let the analyzing plate be turned round

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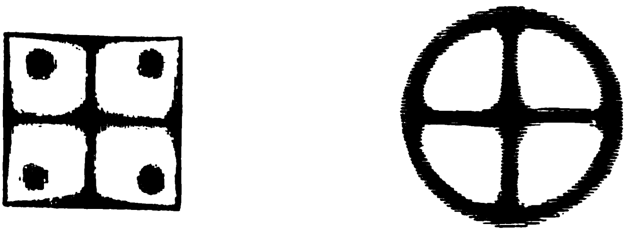
(64) These figures represent the position of the black cross, and coloured circles, in a square and circular piece of unannealed glass.



from right to left, keeping its inclination invariable, and the red colour will change successively to orange, yellow, green, and violet, the analyzing plate acquiring, as it were by its rotation, the power of transmitting these colours in succession; a result which is perfectly explained by supposing that the rays of each of these colours are polarized in different planes. Upon trying different specimens of quartz, M. Biôt, the discoverer of this species of circular polarization, found several in which the very same phenomena were produced by turning the analyzing plate in the opposite direction, from left to right.

§ 260. Upon examining this remarkable property with homogeneous light of different colours, it will be found that, when the yellow ray is transmitted, it becomes fainter and fainter as the plate turns round, till at a certain angle of rotation it totally disappears: the homogeneous red ray disappears at a less angle of rotation, and the homogeneous violet at a greater angle.

The rotation of the plane of polarization is proportional to the thickness of the plate, for all plates cut from the same crystal: and upon placing two plates, one upon the other, which act in opposite directions, the effect will be the same as from a plate having a thickness equal to the difference between the two.

§ 261. Quartz is the only solid substance which has yet been found to possess this property, but some liquids, and even gases, are endued with it.

The essential oil of turpentine turns the planes of polarization from right to left; the essential oil of lemons from left to right. This is the more remarkable, inasmuch as the chemists' art fails to detect any difference in the ultimate composition of these two liquids.

Solutions of camphor in alcohol, and of sugar in water, present the same series of phenomena as quartz, only differing in intensity. The apparatus with which these observations may be made, consists of a metallic tube of sufficient length, closed at its two ends with parallel plates of glass. This tube is filled with the liquid to be examined, and a ray of polarized light is passed through its axis, which is subjected at its emergence to the action of an analyzing plate.

The phenomena are more simple, when a ray of homogeneous light is submitted to the experiment, and a particular glass stained with oxide of copper, answers the purpose perfectly of stopping all but the red ray. The analyzing plate is set in the centre of a graduated circle which, turning with it, indicates the polarizing angle with great accuracy by a vernier upon its edge. Upon looking through such an arrangement, no light penetrates the plate except at this angle, which is greater or less according to the nature of the liquid, the depth of the interposed stratum, or the quantity of the substance in solution.

When liquids are mixed with each other which are either inactive or active in the same or opposite directions, the total effect is always equal to the sum, or the difference, of the separate actions. Even when they pass into the state of vapour, they retain their power, as M. Biôt ascertained by experimenting upon the vapour of turpentine in long tubes.

§ 262. Here, then, we have phenomena dependent, not upon structure,—that is to say, the positions and mutual distances of the particles with regard to each other—but upon the nature of the ultimate particles themselves. This peculiar action of matter upon light may even afford the means of detecting varieties in the nature of substances which elude the more direct means of chemical examination, and M. Biôt has shown that mixtures of the sugar of the cane and of grapes, may thus be recognized and estimated, which would utterly defy the powers of chemical analysis.

He has also applied the property with success, as a test of the value of different samples of the expressed juice of beet-root in the manufacture of sugar, and has thus conferred even a commercial importance upon a discovery, which at first appeared to have as little relation as possible to the arts or conveniences of life.

§ 263. Another curious application of the properties of polarized light, has been made to practical purposes; and such examples furnish an admirable rebuke to those who affect in their ignorance to treat with disdain all such scientific researches, as cannot at once, according to their narrow notions, be rendered *useful*.

It is well known that in dangerous navigations, a commander of a ship will place himself at the mast-head, for the purpose of more clearly seeing the rocks and shoals at the bottom of the sea. Experience has taught him that from this lofty position they are more visible than from the deck. The reason of this is apparent from the common laws of the reflexion and refraction of light: the greater the angle of reflexion, the greater the quantity of light which is turned aside, and the less that which penetrates. The refracted light from the bottom of the sea is not perceptible amidst the glare of that which is reflected to the lower position, for the eye cannot appreciate an addition of less than $\frac{1}{60}$th of the whole quantity which affects it: but at the smaller angle from the higher position, the reflected light is so diminished that the refracted portion makes its due impression.

Now this purpose is still more effectually attained by viewing the objects at the bottom of the sea through a polarizing tube; for at the proper polarizing angle, nearly the whole of the reflected light may be extinguished, and they become perfectly visible by their direct refracted light.

RADIANT HEAT.

§ 264. Radiant heat, as contradistinguished from light, is subject to all the laws of optical phenomena, but is variously affected and modified by different forms of matter, according to the intensity with which it is propagated or projected. The recent experiments and investigations of M. Melloni, have even rendered it highly probable that differences exist between obscure rays of heat which are analogous to the differences between the coloured rays of light; which although they cannot, like the latter, be made the objects of sight, may be established by certain physical properties and relations; just as different physical properties may be found, independent of their colour, in the different rays of luminous spectra.

Radiant heat like light, can pass through a few substances, but is arrested by the greatest number, and is subject to reflexion, absorption, secondary radiation, refraction, and polarization.

§ 265. When the rays of unmixed light are absorbed, they escape the cognizance of our senses: but when the calorific rays are absorbed, they produce the sensation, and universal expansion, of heat. If a perfectly transparent colourless glass tube, be filled with ether, and be placed in the rays of the sun, they will be freely transmitted without raising the temperature of the liquid: but if a piece of charcoal be immersed in the ether, the radiant heat will be arrested, and the temperature will speedily rise to the boiling-point.

It is impossible to examine and experiment upon the light of the sunbeam, without observing that it is accompanied in all its affections by calorific rays. We obtain foci of heat, as well as luminous foci, from concave metallic mirrors and convex glass lenses, according to the laws of reflexion and refraction. The laws, however, of this radiant force are best studied in its projection from terrestial bodies, whose temperature is under our command, and may be varied for the purposes of experiment.

§ 266. The intensity of radiant heat, like that of light, and for the same reason, decreases as the square of the distance from the source of the rays:—thus, if a thermometer protected from the influence of all disturbing causes, be observed to rise a certain number of degrees at one inch distance from a heated surface, it will indicate four times less heat at two inches; nine times less at three inches; and sixteen times less at four inches.

§ 267. The primary law of reflexion at an angle equal to the angle of incidence, is also easily recognized by holding a bright metallic plate before a common fire; the rays of heat may then be turned in any direction according to this law, and tested by our sensation; when we see the image of the fire in the mirror we also feel its heat.

If we fix two concave metallic mirrors, at a distance apart of about ten or fifteen feet, with their axes in the same line, and with their faces parallel and opposed to each other, upon placing a thermometer in the focus of one, it will be found sensible to the effects of a heated body placed in the focus of the other. It is easy to assure ourselves that the effect is owing to reflexion, and not to the direct radiation of the heated body, by removing the thermometer out of the focus, and approaching it towards the source of heat when it will be found to fall; or the same return to its original state may be produced by placing a screen between the thermometer and its own mirror; when the reflected rays will be cut off, although the direct communication with the radiating body will still be open. In the same way when a red-hot iron ball is placed in one focus, a piece of paper will be scorched in the other, and gunpowder and phosphorus may be inflamed even when the temperature of the ball is below ignition (65).

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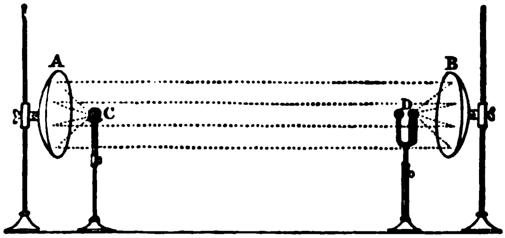
(65) The annexed figure shows the disposition of the apparatus. A and B are the two polished metallic mirrors. The hot iron ball is placed in the focus, C, of the mirror, A, towards which it radiates its heat. The diverging rays are reflected in a parallel direction upon B, by a second reflexion from which they are rendered convergent, and fall upon the thermometer, D, placed in the focus to receive them.



The heated body placed in one of the foci of these conjugate mirrors throws off its rays in all directions, and those which strike upon the surface of the nearest mirror are reflected, according to the law which has been so often stated, in a parallel direction upon the surface of the second mirror, where they undergo a second reflexion, and according to the same law are made to converge at the second focus, and there act with their concentrated energy.

§ 268. Reflexion from the concave surface of a hollow cone, also causes rays of light or heat to converge to a focus, and those who have not the command of conjugate mirrors, such as have been just described, may easily verify the above results simply by a sheet of gilt paper, rolled up into the form of a truncated cone with the metallic surface inwards. If a hot ball be placed at the large extremity of this cone, the radiant heat will be reflected to a focus beyond the smaller end, and phosphorus, &c., may be fired.

§ 269. Bright metallic bodies being the best reflectors of heat, in the experiments above described, the temperature of the mirrors is not appreciably raised; but if their surfaces be dulled, as by coating them with lamp-black, the rays are absorbed by the mirror which is the nearest to the heated body; it becomes hot, and a small and almost inappreciable quantity is transmitted to the second mirror. Bodies, however, which thus absorb radiant heat, throw it off again by a secondary radiation, and scatter it in every direction as from a centre; and it has been ascertained by the beautiful experiments of Sir John Leslie, that the best absorbents of heat are the best radiators.

Heat propagated by regular reflexion, loses none of its intensity by increasing the distance which it has to traverse, except a minute quantity which is due to the absorption of the medium through which it passes; but when propagated by secondary radiation, it decreases directly as the square of the distance. Two portions, therefore, under these different circumstances, may easily be distinguished from each other by these different properties.

§ 270. These properties, as well as that of reflexion, depend entirely upon the surfaces of bodies. Sir J. Leslie obtained most of his results with the simple apparatus of a cubic tin cannister, which he heated by filling it with boiling water, and then by coating three of the sides with different substances, he compared their several effects upon a delicate thermometer, placed at the same distance from each, with that of the fourth side which was left in its bright and polished state. By these means he found that taking the quantity of heat radiated by lamp-black as 100, the radiating power of a surface covered with glue was 80, and of the clear metal 12. The following table was also constructed from Professor Leslie's experiments:—

TABLE XXX. *Radiating Powers.*

Lamp-black	100	Tarnished lead		45
Sealing-wax	95	Clean lead		19
Writing paper	98	Polished iron		15
Crown-glass	90	Tin	polished	12
China ink	88	Gold		
Read lead	80	Silver		
Plumbago	75	Copper		

He also found that the direction of the lines by which the surface was roughened had a considerable effect upon the result. He scratched a bright metallic surface with a number of lines in one direction, and found the force of radiation increased: he then scratched a similar surface with the same number of lines, half of which crossed the others at right angles, and obtained a still greater effect. The power of projection seemed to depend upon the number of points produced.

§ 271. M. Melloni has lately ascertained by experiment, that these differences in metallic bodies do not arise from differences in the state of their surfaces, but from changes in their densities. To determine this, it is necessary to make the observations with metals which are not easily oxidizable; for the thin coat of oxide which forms upon tin, or zinc, or brass, is known to radiate much better than the metals themselves. He formed two vessels of pure silver, one of well-hammered plate, and the other of cast metal slowly cooled. He polished one side of each very highly, and the other he scratched with emery paper in one direction only, and filling them both with hot water, he found the following difference:—

10°	For the polished face of the hammered metal.	13°.7	For the polished face of the cast metal.
18°	For the scratched face of the same.	11°.3	For the scratched face of the same.

Comparing these results it will be found;—1st., That in the case of the polished surfaces, the cast metal radiated nearly ⅓rd more than the forged; showing the superiority of the lesser density;—2dly., That in the case of the scratched surfaces, not only does the hammered metal show an augmentation of radiant power of $\frac{4}{5}$ths, but the cast metal a diminution of nearly $\frac{1}{6}$th.

The latter unexpected effect arises, according to M. Melloni, from the compression of the soft surface of the cast metal by the action of the hard emery.

§ 272. The relation of the powers of reflexion, absorption, and radiation, and the equality of the two latter in similar surfaces, is well shown by an experiment of Dr. Ritchie. He placed a hollow metallic vessel filled with hot water, between the two metallic discs of an air-thermometer. The surface of one disc was bright and polished, and of the other covered with lamp-black. One of the surfaces of the heated vessel was also bright and polished, and the opposite surface similarly blackened. When the apparatus was so arranged that a black was opposed to a metallic surface, no effect was produced upon the liquid of the thermometer; but when the blackened surface of the heated vessel was opposed to the blackened disc, the expansion of the air indicated a strong transmission of heat. In the first position, the good radiating surface of the heated vessel was opposed to the good reflecting disc of the thermometer, and its bad radiating surface to the good absorbent surface, and the actions were exactly balanced: but in the second position, the good radiating surface was opposed to the good receptive surface, and the two bright metallic surfaces to each other, so that everything favoured the transmission of heat on one side, and stopped it on the other side, and the liquid of the thermometer instantly indicated the inequality.

§ 273. These principles may be readily illustrated by easy experiments, or by the results of common experience. If we take two equal tin vessels, brighten the surface of one, and blacken the other, we shall find upon filling them with hot water, that the water in the blackened vessel will cool much faster than that in the bright vessel. The water in a bright silver tea-pot will retain heat much longer than water of the same temperature in one of earthenware; and hence the superiority of the one over the other for preparing the infusion. The furniture of the kitchen will also afford abundant apparatus for illustrating the principles of radiation, absorption, and reflexion, and their economical applications. If the bottom of the kettle be bright, we shall scarcely be able to boil the water which it contains; but the moment it becomes covered with soot the heat freely passes into it. If the whole of its surface be blackened, the water will soon cool when removed from the fire, and it is in its most efficient state when its sides and top are bright, and its bottom coated. By the meat-screen and the Dutch oven the radiant heat of the fire is reflected, and concentrated upon the operations which are carried on behind them; and innumerable other instances might be adduced in which experience and observation had probably long anticipated the conclusions of experiment and science.

Pipes for the conveyance of hot water or steam should be kept perfectly bright and polished; while at those parts where they are destined to give out the heat to the surrounding atmosphere they should be roughened, or coated with some good radiating substance. By attending to such circumstances, which might to the uninformed appear trifling and unimportant, the consumption of fuel in the steam-engine itself has been greatly economized.

The thinnest coating of gold leaf covering the finger, will enable a person to approach it within a very small distance of a red-hot iron or other incandescent body; while, if unprotected, it would be burnt at ten times the distance. And the same reflecting power may be rendered visible by gilding some letters upon a sheet of paper, and holding a red-hot iron over them, when the uncovered intervals will be scorched, but the letters themselves will be untouched and conspicuous.

§ 274. The radiation of heat is one of the most important processes in the economy of nature, and it is one of the means by which equilibrium of temperature is brought about. Not only does heat travel from a hot to a cold body by the processes of conduction and convection, which we have before examined, but it is projected from the one and absorbed by the other, at a rate dependent upon the state of the surfaces of the two. In every assemblage or system of bodies, as for instance the various objects in a room, there is a tendency in each to radiate its heat; which, if met by an equal force or exchange in others, or in the walls of the apartment, is balanced or restrained; but if any inequality exist in the system, the projection takes place towards the weaker point till the balance is restored by absorption.

The same radiation takes place upon a large scale from all the substances upon the surface of the earth towards the regions of space; which, if not met and counteracted by the radiation from the sun, would soon annihilate all organic being by the rigors of an eternal frost.

§ 275. We may easily obtain evidence of this tendency by placing in the focus of a concave metallic mirror the bulb of a thermometer, covered with some good radiating substance, as the short white fibres of wool or cotton. By turning this apparatus towards the clear sky, the thermometer will fall several degrees. It is protected by its position from the radiation of surrounding objects, and its own radiant heat is projected towards the clear space, or falling upon the concave surface of the mirror, is reflected in parallel lines in the same direction. This effect is produced even while the sun is above the horizon, provided the mirror be turned from the direct rays of that luminary; and at night a depression of seventeen degrees below the temperature of the air and surrounding objects may commonly be produced. Perfect stillness of the atmosphere is necessary, and perfect transparency also, for otherwise the balance of temperature is soon restored by convection, and the slightest mist destroys the effect by a counter-radiation.

§ 276. It was upon these principles that Dr. Wells first explained the formation of *dew* in one of the most beautiful experimental essays which ever graced the annals of inductive philosophy. He ascertained that the formation of this important phenomenon was always preceded by the cooling of the body, upon which it was deposited, below the temperature and dew point of the air by radiation. Hence it is that the best radiating substances, such as the fibrous and filamentous textures of vegetables, collect this moisture most abundantly, and the short-mown grass-plat will be covered with it, while the gravelled walk, or compact road by its side, will remain perfectly dry: and hence it is that dew never forms on a cloudy night, or when there is wind enough to restore the balance of temperature by its circulation.

§ 277. If in one of the foci of the conjugate mirrors before described, a piece of ice, or a glass flask filled with a freezing mixture, be placed instead of a heated body, the thermometer in the other focus will indicate a depression of temperature; and the experiment has sometimes been referred to as proving *cold* to have a positive existence, distinct from heat; but the phenomenon is easily explicable upon the principles which we have already explained, without reference to any new hypothesis. In the new arrangement, the thermometer is the hotter body, and radiating its heat upon the nearest mirror, the rays are projected upon the second, and collected in the focus, where they are absorbed by the ice; and as no adequate return is made, the temperature of the thermometer necessarily falls.

The effect is exactly the same as that of radiation directed into clear space, just described, which itself was referred by Sir J. Leslie, to cold pulses shot downwards from the sky.

§ 278. Radiation, however, was ascertained by Sir H. Davy to proceed with greater energy in vacuo than in the air. He, by means of the voltaic battery, ignited charcoal placed in the focus of a small mirror confined in the exhausted receiver of an air-pump. The receiver being exhausted to $\frac{1}{120}$th, the effect upon a thermometer placed in the focus of another mirror below, was nearly three times as great as when the air was in its natural state of condensation.

§ 279. It has long been known that the heating power of the sun's rays depends upon the colour of the surfaces upon which they fall; and that dark and black bodies are more heated than those which are of light tints, or white. The fact was proved by Dr. Hooke and Dr. Franklin, who placed pieces of cloth, of similar texture and size upon snow, allowing the sun's rays to fall equally upon them. The dark specimens always absorbed more heat than the light ones, and the snow beneath them melted to a greater extent than under the others; and they remarked that the effect was nearly in proportion to the depth of the shade. With regard to this experiment, the different colours stood in the following order, —Black, blue, green, purple, red, yellow, white.

It is probable that the absorption of some kinds of terrestrial heat may also be affected, in some degree, by the colour of the objects upon which the rays may fall; but, generally speaking, the absorption and radiation of terrestrial heat are dependent much more upon the texture than the colour of the surfaces upon which it impinges, or from which it emanates.

§ 280. We have now to inquire how radiant heat is affected by its passage through such bodies as it can penetrate and traverse. All the ordinary phenomena which we observe, take place through the medium of the atmosphere, and radiation will proceed through any gaseous medium. The experiment of Sir H. Davy has however just been referred to, to prove that it proceeds with least obstruction in vacuo. Observation has also proved that the intensity of the solar rays is greater upon the summit of a lofty mountain than at its base; and it has been calculated that about one-fifth of the solar heat is absorbed in passing through a column of 6000 feet of the purest air.

As it is by the passage of light through different transparent media that we distinguish different kinds of luminous rays, so by the same means we are enabled to detect different kinds of calorific rays.

§ 281. Sir Wm. Herschel, in examining the solar ray by means of a prism of flint-glass, found the greatest heat in the red ray, or even in the dark space a little beyond it; and concluded that radiant heat was less refrangible than the least refrangible of the rays of light. Professor Seebeck subsequently ascertained that the place of the maximum of temperature in the solar spectrum depends upon the chemical composition of the substance of which the prism is made. With a hollow prism filled with sulphuric acid, it fell within the limits of the orange space, and with water within those of the yellow.

§ 282. In experimenting with colourless and perfectly-polished and transparent glass, one striking difference immediately occurs between solar heat and the radiant heat of terrestrial bodies; it allows the rays of the former, like the rays of light, to pass through it with little obstruction, while it almost wholly arrests the progress of the latter. The rays of heat, as well as of light, are concentrated in the focus of a concave metallic mirror, and the greatest heat which has ever been produced by art has thus been accumulated. The effect is little lessened when the mirror is formed of silvered glass, in which case the rays which are reflected from the bright metallic surface pass through the interposed substance of the glass before they are collected. On the other hand, if the metallic mirror be held before a common fire, a burning focus will be easily found; but with a glass mirror the light of the fire will be reflected, but not its heat. In a similar way, glass lenses refract both the light and heat of the sun, and hence are familiarly distinguished as burning-glasses; but when held before any source of terrestrial heat, the most delicate air-thermometer will scarcely be affected.

The principal effects which we have previously described of the reflexion of dark heat from the conjugate mirrors are immediately arrested by the interposition of the thinnest glass-plate. This property of glass is sometimes usefully employed where it is desirable to see the light of a fire without being incommoded by the heat; and glass screens are used to protect the eyes when it is necessary to inspect the action of a hot furnace.

The radiant force, however, is not lost by this absorption of the glass: it receives a new direction; the glass itself becomes hot, and begins to throw off heat by secondary radiation.

§ 283. This distinction between solar and terrestrial heat is far from being absolute as was at one time supposed; for by delicate experiments it has been found that glass will arrest some of the former rays, while, on the other hand, it will allow some of the latter to pass. It has also been ascertained that the quantity of terrestrial heat which may be transmitted varies with the nature of its source: from a good radiating surface of the temperature of boiling water it is scarcely appreciable, while from the flame of a gas-lamp it may be measured by the air-thermometer. M. De Laroche also made the discovery that the heat which has passed through one plate of glass is less subject to absorption when passing through a second.

§ 284. The difference between radiant heat or light, and heat in its other condition, is strikingly illustrated by the combustion of a flame of hydrogen and oxygen gases in which no solid matter is concerned. The result is the vapour of water, and the disengagement of the greatest heat which art can command; but it is accompanied by very little light, and if a convex lens be held before it, the radiant heat which will pass through it will scarcely affect the most delicate air-thermometer. If a piece of solid matter, capable of resisting its action, such as a wire of platinum, be held in it, radiation will immediately take place. A piece of lime thus presented to the flame undergoes no chemical change, but emits a light which almost rivals that of the sun; and radiant heat is at the same time projected of sufficient intensity to penetrate the lens, and to inflame phosphorus at its focus.

§ 285. We are indebted to M. Melloni for almost all that we know, with accuracy, of the passage of radiant heat through different translucent substances. The memoirs in which he has recorded his experiments and deductions have been most justly honoured with the Rumford medal of the Royal Society, and they present a model well worthy of the imitation of those who are engaged in similar physical investigations.

He has ascertained that the power in bodies of transmitting rays of heat is by no means proportioned to their transparency, or their power of transmitting rays of light; and amongst crystallized bodies in particular, he has found that some which are highly transparent intercept nearly the whole of the calorific rays, while others act in a manner directly contrary. These properties are invariably manifested, whatever be the temperature of the source, and become yet more singular at low temperatures; for in the latter case it is found that the ordinary heat of the hand will pass through a solid body of several inches in thickness. Liquid chloride of sulphur, of a deep red-brown colour, will, out of 100 rays, allow 63 to pass; while an equal thickness of colourless spirit of turpentine will only transmit thirty-one; of sulphuric ether, twenty-one; sulphuric acid, seventeen; and of distilled water, only eleven: the case is the same with solid bodies. Different kinds of glass vary in their powers of transmission, from sixty-seven per cent. in flint-glass to forty-nine per cent. in crown-glass: while perfectly diaphanous rock-salt will transmit 92 out of every 100 rays; and equally diaphanous alum only twelve. To distinguish those bodies which possess a capacity for calorific transmission, from those which possess a capacity for luminous transmission, he has proposed the term *diathermanous* for the former, as analogous in form to the epithet *diaphanous*, applied to the latter. In one experiment he employed a plate of alum, well polished, and perfectly transparent, only .06 inches in thickness, and compared it with a plate of smoky quartz 3.38 inches thick, which was of so decided a brown colour that the large letters of a printed page, placed in the fullest light, could not be traced through it; and found that the former allowed only six per cent. of the rays to pass through it, while the latter afforded a passage to nineteen per cent. He also found that the perfectly opaque glass employed in the construction of mirrors, for experiments upon the polarization of light, was diathermanous enough to transmit a considerable quantity of calorific rays: on the other hand, sulphate of copper, which is of a blue colour, and strongly *diaphanous*, is perfectly *athermanous*.

§ 286. These striking differences in bodies of the same aspect, seem to arise rather from structure than from the chemical composition of the molecules, for a block of common salt, being divided into flakes, instantly arrests calorific radiation, and the transmissive power of water is only increased from eleven to twelve, by dissolving in it either alum or rock salt, two substances which in their solid state are at the opposite extremities of the scale of transmission.

M. Melloni performed all his experiments with an apparatus of extreme delicacy, the construction and application of which constitutes not the least interesting part of his work: but such as have not a thermoscopic apparatus may easily satisfy themselves that rock salt transmits almost all the radiant heat that falls on its surface, by fixing vertically on the same stand a plate of this substance, and a plate of glass or alum of the same dimensions, and by bringing the stand quite close to the fire of a stove. If it be allowed to remain in this state for five or six minutes, the glass will become burning hot, while the rock salt, if applied to the most tender part of the hand, will produce no sensation of warmth. This difference may be rendered visible by placing a piece of wax on each of the plates; that on the glass will soon begin to melt, while that on the salt will remain quite solid.

The greatest part of the experiments may also be repeated by means of a large air-thermometer bent twice at right angles; between the blackened balls of which a stand is placed, for the reception of the source of heat and the intervening plates. The liquid will be depressed on that side on which the heat most freely radiates.

§ 287. The results above detailed were obtained from the burner of an argand lamp; but M. Melloni found that different effects were produced from different calorific sources. The four which he compared together were the flame of oil without the interposition of glass; platina wire kept in a state of incandescence, by means of the flame of a spirit lamp, (both of which are luminous); a plate of copper heated to the temperature of 732°, and a vessel of thin copper blackened on the outside filled with boiling water, (both of which were non-luminous); some of the principal results are shown in the following table:—

TABLE XXXI. *Of Diathermancy.*

Names of the interposed substances—common thickness, 0.102. In.	Naked flame.	Incandescent Platinum.	Copper at 732°.	Copper at 212°.
Rock salt . . .	92	92	92	92
Iceland spar . . .	39	28	6	0
Mirror glass . . .	39	24	6	0
Rock crystal (colourless) .	38	28	6	0
Ditto (smoky) .	37	28	6	0
Citric acid . . .	11	2	0	0
Alum	9	2	0	0
Pure Ice . . .	6	0	0	0

§ 288. Thus it appears that rock salt, successively exposed to radiation from different sources, always transmits immediately the same quantity of heat, (and it is the only known substance which thus acts.) A plate of any other diathermanous substance will, under the same circumstances, transmit quantities less considerable in proportion as the temperature of the source is less elevated: but the differences between one transmission and another, decrease as the plate on which we operate is more attenuated. Whence it follows, that the calorific rays from different sources are intercepted in a greater or less quantity, not at the surface and in virtue of an absorbent power varying with the temperature of the source, but in the very interior of the plate, and in virtue of an absorbent force similar to that which extinguishes certain species of light in a coloured medium.

§ 289. In extending this observation to the solar rays, M. Melloni found that the quantity of heat intercepted by increasing the thickness of the transparent medium is greater for the less refrangible than for the more refrangible rays: that is, that while the thinnest possible pellicle would permit as much per cent. of the heat accompanying the red ray to pass through it as of the violet ray, if the thickness be increased, a much larger per centage of the former will be stopped than of the latter; whence he concluded that the refrangibility of a heating ray is a measure of its intensity. The rays of heat which are separated by a common prism do not undergo the same action upon passing through a layer of water: the most refrangible rays, or those towards the violet end of the spectrum, pass undiminished; while the less refrangible, or those in the red ray, are entirely stopped by that liquid. Thus, the changes in the maximum of temperature in the solar spectrum, when different liquids were employed by Professor Seebeck, are accounted for.

§ 290. The refraction and constant transmission of the calorific rays from any source through rock salt being established, it is easy to see the use which may be made of this substance in carrying on the investigation with regard to the nature of radiant heat. When formed into lenses and prisms, it will act upon calorific rays in a manner perfectly analogous to that in which optical instruments act upon luminous rays. The feeblest emanations may thus be concentrated to a focus, or propagated to a distance; and in this manner we may, with the aid of a common differential thermometer with small balls, obtain very decided indications of the heat issuing from a vessel filled with tepid water and placed at a great distance. It constitutes, to use M. Melloni's expression, *the true glass* of radiant heat. All other transparent bodies are but partial and incomplete transmitters of heat, totally intercepting calorific rays of a certain kind, just as coloured media intercept coloured rays of certain kinds. All examinations of the nature of solar heat with common prisms of glass, water, alcohol, &c., are necessarily as fallacious as any attempt would have been to analyse solar light with prisms formed of coloured glass.

§ 291. Amongst the calorific rays of the sun there are some which have a resemblance to terrestrial heat, and amongst the calorific rays of flame some are found similar to the heat of the sun. The differences observed between solar and terrestrial heat, as to their properties of transmission, are therefore to be attributed merely to the mixture, in different proportions of several kinds of rays.

The small quantity of heat which emerges from alum is abundantly transmitted by all diaphanous colourless plates, and suffers no appreciable loss when the thickness of the plates is varied within certain limits; with regard to transmission, these rays in fact, bear a close resemblance to those of solar heat. They also resemble the latter in the decided influence which colour has upon their absorption. When the rays of a naked flame were made to fall upon similar thermoscopic surfaces covered with lamp-black, and Spanish white mixed with gum-water, the effect of the white, as compared with the black, was as 80.5 to 100; and it was the same when a screen of rock-salt was interposed; but when rays which had been previously passed through a screen of alum were employed, the effects were as 42.9 to 100. Professor Powell has ascertained that colourless glass acts in the same way, though with somewhat less energy.

§ 292. M. Melloni has remarked, that this specific difference in the rays of heat is manifest upon the great scale of natural phenomena in the differences of their absorption by snow. It has long been observed that snow, which lies near the trunks of trees and tufts of shrubs, melts much more rapidly than at a distance from them. This is not owing to any proper heat of the vegetating bodies, for the same thing happens around dead bushes and dry poles; and the greater the number of branches, and the smaller the twigs, the greater is their thawing influence. The effect commences on their south sides, and gradually extends by the west, till it reaches round to the north. Hence, it appears that it is due to the heat of the sun, directly communicated to the trunks and branches of the trees, and then radiated from them to the surrounding surface. Up to the time of M. Melloni's discoveries, it was quite impossible to account for this secondary radiation having more power than the primary one from which it was derived. He has, however, shown by the most decisive experiments, that the secondary rays from the trees are much more abundantly absorbed by snow and other white substances than the solar rays themselves.

If the rays of a naked lamp be concentrated by a lens, and made to fall upon a thermometric surface covered with white lead, an effect will be produced which may be designated as 15°; but if a sheet of thick paper, of a deep grey colour, be interposed in the passage of the rays close to the thermoscope, the effect will rise to 33°. Here we may suppose, that of 100 direct rays which fall upon the white surface, 10 only are absorbed, and the rest reflected. When the paper is interposed it becòmes itself heated, and radiates, perhaps, only 25 to the same surface; but of these, 5 only are reflected, and 20 absorbed.

The different effect upon snowof rays of heat from different sources, may be shown by a still more direct experiment. Let a differential thermoscope be placed between an Argand lamp and a blackened copper surface, heated by a spirit lamp to 752°, so as to be in *equilibrio* between them; which may be effected by approaching the instrument nearer to the feebler source of heat than to the other. Having ascertained the position of equilibrium, let the thermoscope be removed, and a tube divided into two by a diaphragm, and filled at each end with newly-fallen snow, be exactly placed in its position with one face presented to each of the calorific sources. Notwithstanding the equality of the intensity of the heat, as measured by the thermoscope in this position, the snow in the tube opposed to the heated copper will melt much faster than that in the other, and will generally disappear in half the time.

The experiment may be made still more simply by suspending over a surface of snow, and close to it, a disc of thin card, covered on both sides with lamp-black: if the rays of an Argand lamp be made to fall upon it, the surrounding snow will be unaffected, but a cavity will be quickly thawed under the card. If the heated copper plate be now substituted for the lamp, the phenomena will take place in the inverse direction; the melting of the snow will be more abundant in the parts exposed to the direct radiation than under the disc, so that in a short time there will be a protuberance in the latter situation instead of an excavation.

In the first of these cases, the heated card emits rays much more absorbable than the direct rays of the lamp; and hence it follows, that the snow is melted in much greater abundance under the shadow of the disc than elsewhere, notwithstanding the quantity of the heat is less. In the second case, when the calorific source and the card both emit rays of the same nature, and equally absorbable, the disc must, by its interposition, diminish the effect of the direct radiation, and protect the snow in the part which it screens.

§ 293. With regard to the colour of different media, M. Melloni found that glass of the different tints of the prismatic spectrum acted in the same manner as colourless glass, but with diminished power; with the exception of green glass (coloured with oxide of copper), which proved to be more transparent for the rays of small refrangibility (or emanating from a source of low intensity), than for those of greater refrangibility (or those from a more intense source). The difference between the quantity of heat from an Argand lamp and that from an incandescent spiral of platinum wire, was about half with all the kinds of glass except green; but, in the case of green glasses, the difference was little or nothing. Hence, he concludes that green glass is the only kind which, so to speak, has *coloration* for heat; the others acting upon it only as a more or less transparent glass of uniform tint does upon light.

By passing the rays of the sun first through a stratum of water, and then through green glass, he succeeded in sifting the whole of the heat from the light. The emerging beam had a greenish tint, but, when concentrated by a lens of rock-salt to the intensity of the original ray, had not the slightest effect upon the most delicate thermoscope.

§ 294. The polarization of heat, though the experiments by which it has been demonstrated are of a still more delicate nature than those which we have just examined, rests upon as certain foundations as its refraction. Heat was first shown by M. Berard to be susceptible of this modification by reflexion. M. Melloni, however, failed at first in obtaining any indications of polarization, either by this means or by transmitting obscure radiant heat through plates of tourmaline. Professor Forbes succeeded in these experiments, and also showed that it may be produced by plates of mica: and M. Melloni has since thoroughly investigated the subject, and explained his previous failure.

A great difficulty presents itself in studying the polarization of heat by tourmalines in their feeble calorific transmission, which varies with their quality. These differences depend upon the diathermancy of each species of the mineral; that is, they arise from different species being each permeable to a differently constituted calorific stream. Of every 100 rays transmitted by a pair of tourmalines with their axes parallel, about 22 disappear by crossing the axes. This proportion suffers no very decided change in the rays transmitted by common glass, or glass of any prismatic colour except green, when it is reduced to $\frac{8}{100}$. When water, on the contrary, is employed, the quantity of heat which is polarized, after transmission, amounts to $\frac{22}{100}$: showing an analogous difference in the polarization of different kinds of heat to that which we had previously found in their refraction; and in this presenting a marked distinction from the polarization of light.

ELECTRICITY.

§ 295. We will proceed now to inquire into the nature and laws of those forces which we have already indicated and named *electrical*, from the *electron* or amber in which they were first observed by Thales, 600 years before the Christian era. The more striking phenomena of lambent flames upon the mast-heads of vessels in a storm, or lights upon the spear-points of soldiers, and the flash of lightning, had been also observed with feelings of dread and superstition, but were little supposed, in those early days, to have any thing in common with the alternate attraction and repulsion of minute particles of dust by this rare substance after it had been subjected to friction. It was not till 2200 years afterwards, that the same property of attraction, accompanied under favorable circumstances by flashes of light, was observed to be possessed by glass, sulphur, and sealing-wax, and that the foundations of electrical science were laid by Mr. Gilbert. We are indebted to active observation or experiment for the whole of the superstructure; mere passive observation, or common experience, having had but little influence upon its progress. Electricity is as widely diffused, as energetic in its character, and at least as important in the economy of the material universe, as heat itself; but its properties are more recondite; and necessity has not given to the human race that early command over this power, upon which its very existence has depended in the latter case. Such a command will probably result from the higher exercise of the intellectual faculties of man, and may be destined to requite his patient industry with the acquirement of power, of which only inadequate anticipations can, as yet perhaps, be formed.

§ 296. It will be remembered that we traced the origin of heat to five principal sources; and from four of the same sources we also derive the new force which we are about to examine; whilst analogy, as well as the uncertain results of vague experiments, lead us to believe that the fifth, or the solar rays, will hereafter be found capable of imparting this subtle influence. It is freely evolved by the mechanical action of heterogeneous substances; still more abundantly by chemical action; it is a product of animal organization; and as electricity under certain conditions is capable of evolving heat, so heat, on the other hand, is capable of exciting electricity. Like heat, it adds nothing to, and subtracts nothing from, the weight of bodies in which it is excited; but unlike heat, it is not opposed to cohesion, and does not increase the volume of homogeneous masses, or loose the chain which binds their particles together. It is capable of acting upon masses of matter in opposition to gravity, and it is also capable of the most energetic influence upon its constituent atoms. Every form of matter may be excited to its action, and it may be transferred from one portion of matter in which it has been called forth to another previously in a neutral state.

Our present purpose, which will lead us to inquire into the modes in which this force distributes itself, and in which its equilibrum is maintained amongst the particles of ponderable matter, or into the laws of ELECTRICAL STATICS, will best be answered by confining our attention mainly to its mechanical developement, or excitation by friction.

§ 297. The apparatus we shall first describe is of extreme simplicity, but the instruction which we derive from it is of the greatest importance.

We have already seen (§ 14) that if we suspend some light substance, such as a feather or a pith-ball, by a silk thread, and then approach it with a dry glass tube, which has been rubbed with silk, the suspended substance will be attracted to the glass tube from a distance, and adhere to it for a moment, but will afterwards recede from it; and, after its separation, so far from the glass exerting any attraction upon it, it will strongly repel it from its surface. If we substitute a stick of sealing-wax for the glass tube, and rub it with a dry warm flannel, we may produce the same phenomena of attraction and repulsion upon a fresh feather; and in the same order. But, now, if we present the excited wax to the feather which has received the repulsive property from the glass, or the excited glass to the light substance which is in a state to be repelled by the wax, strong attraction will be manifested in both cases.

Moreover, we find from experiment that not only does the originally excited glass or wax attract or repel those light portions of matter, but they communicate by contact the same properties to them: so that two feathers, after having been attracted, will not only be repelled by the wax or glass, respectively, but will repel each other, and their component fibres will become self-repulsive: but two feathers which have received the property from the different substances, though self-repulsive, will strongly attract each other. This transfer of power, it must be observed, is very different from any process of original excitement (66).

§ 298. Simple as are these phenomena, they comprise the first principles of electrical science. From them we learn that the friction of glass and resin communicates to these substances a state of activity with regard to other bodies, which is similar in the two cases, but opposite in its nature: that this state of activity once excited in them by friction, they are capable of communicating to other bodies by simple contact, and that it is manifested in all cases by the mutual repulsion of similarly active bodies, and the mutual attraction of oppositely active bodies.

Now these two states of activity, it is obviously necessary to distinguish by some appropriate designation, and they might properly be termed the *vitreous* and *resinous* states from the two substances which were first observed to possess the power of communicating them. But in a subject so remote from the illustrations of common experience as is that of electricity, it has been found necessary to do more than this: to adopt some hypothesis with regard to the subtle influence thus called into action, which may

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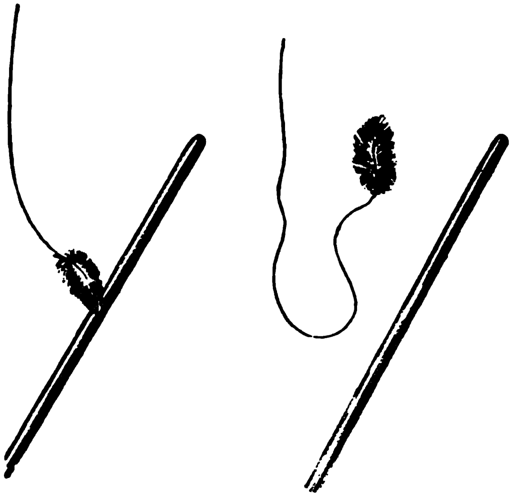
(66) The annexed figure will convey an idea of the feather when



in its natural state attracted by the excited glass, and when in an electrified state repelled from the similarly electrified rod.

serve as a clue to guide the student amongst the multiplicity of its phenomena. When he is informed that there are two such theories, upon which the facts may be explained with equal probability, he will need no other caution to distinguish between the importance of the facts and inductions, and the thread which is employed to string them together.

§ 299. It was imagined by M. Du Fay, that the opposite electrical forces were peculiar to certain kinds of matter; that they were referrible to two highly-elastic, imponderable fluids, the particles of which were self-repulsive but attractive of each other; and that one which he called the vitreous electricity was always elicited from glass, and the other which he termed resinous electricity from resinous bodies. In the form in which the hypothesis of two fluids, which goes by his name, is now adopted, it is greatly indebted to the observations and modifications of Mr. Symmer, who showed that when two bodies are rubbed together, both become excited; and that one of them always possesses the vitreous, and the other the resinous virtue. The two fluids exist in all unexcited bodies in a state of combination and neutralization, when no electrical phenomena are apparent. Friction occasions the separation of the two fluids, and the electrical action continues till an equal quantity of that kind of electricity which has thus been withdrawn from the other, has been restored and re-united with it.

§ 300. Dr. Franklin proposed a different and no less ingenious explanation of electrical phenomena, in some respects more simple than the preceding; dependent also upon the properties of an imaginary highly elastic fluid, which, upon his supposition, was single, and pervaded all matter. This fluid is self-repulsive, but attracts the ultimate particles of matter, which the hypothesis further requires should be considered as self-repulsive when deprived of their natural portions of the electrical fluid. The opposite states of electrical excitement, according to this view, depend upon the increase or diminution of this elastic fluid. When a glass tube is rubbed with a silk handkerchief, the electrical equilibrium of the fluid in the two substances is disturbed; the glass acquires more than its natural quantity, and is overcharged: the silk retains less than its natural quantity, and is undercharged. Thus, electrical repulsion takes place between two bodies both of which contain more or less than their natural quantity of fluid, and electrical attraction is only excited between two bodies, one of which contains more or less than the other.

According to the theory of Du Fay, the two states are denominated *vitreous* and *resinous;* according to the theory of Franklin, they are distinguished as *positive* and *negative*.

§ 301. It is quite obvious that both these hypotheses cannot be true; and it is highly probable (indeed some of those best qualified to judge would say that it is certain,) that neither of them presents us with the real process or mechanism of the phenomena. The progress of science begins clearly to indicate that the whole class of electrical facts will one day be included in some higher generalization than either of those by which they are at present grouped together; and indeed an attempt has been made (and according to mathematicians, who are best qualified to judge of such high exercises of reason, not without success,) to connect, in one general theory, all attractive and repulsive forces, not excepting the universal force of gravity itself*.

Such views, however, must not be presented to beginners in science, and probably it will not be in the present age that the teacher will be able to dispense with one or other of the scaffoldings by the assistance of which the fabric of electrical science has been built up to its present dimensions and proportions. The hypothesis of two fluids has had the advantage of having been submitted to mathematical investigation by M. Coulomb and M. Poisson; but even in the mathematical investigations it is easy to substitute one theory for the other by a very simple transformation of the formulæ.

In making the legitimate use of either theory to assist him in attaining *clear ideas* of the connexion of the phenomena, the student should never forget that such hypothetical fluids may have no real existence, and that the peculiar actions which he is called upon to contemplate may be referrible to powers with which matter may have been endowed, without the intervention of any such medium as has been imagined. Indeed, the late rapid advance of the science seems rather to countenance this more simple view of the subject; and one of the greatest difficulties with which the teacher has to contend at present is a certain confusion of view and of language which almost necessarily attends this transition state. After this explanation, however, it is to be hoped that no difficulty will be felt at the indifferent employment of the terms *vitreous* and *resinous*, or *positive* and *negative*, to denote those peculiar states of matter by which the phenomena which have been just described are produced.

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* MOSOTTI. *Sur les Forces qui régissent la Constitution intérieure des Corps.*

It is a necessary consequence of either of the hypotheses which we have just stated, that one species of electricity can never be excited without a simultaneous production of the other; and, in fact, the opposite electrical states are always such as exactly to neutralize each other in the rubber and the body rubbed. This conclusion is quite borne out by the results of experiment. Even with the glass tube, and silk, we shall find that it is not only the glass, but the silk also, which after friction attracts the feather; and after the feather has been repelled by one, it will be strongly attracted by the other. We shall presently find more perfect means of demonstrating the exact equality of the opposite forces.

§ 302. After either electrical state has been conferred upon a body, for instance, on the glass by friction, or on the feather by contact, it will very slowly return to its natural state in a dry atmosphere, unless it be touched with some other substance; but the nature of the substance brought into contact with it is by no means indifferent to the result. The naked hand will speedily remove the electricity, or any metallic body still more readily; but dry glass, resins, silk, sulphur, will not prove effective. From this difference in their power of conveying or conducting away the electricity, bodies have been divided into two great classes of *conductors* and *non-conductors*. In the former, the elastic fluids are supposed to travel with little or no impediment, and with a velocity infinitely exceeding that of the similar propagation of heat, and only comparable with light itself; while in the latter their passage is obstructed; they seem to adhere to their substance, and to be incapable of transmission from particle to particle.

Although we may thus classify all substances into conductors and non-conductors of electricity, we shall, however, find the two classes passing by insensible gradations one into the other. There is, in fact, a progressive order in which all bodies may be arranged, beginning with that substance which possesses either property in the most perfect degree, and proceeding through the gradations of other substances to the opposite extremity of the scale. In the following Table, the left hand column commences with the most perfect conductors, and ends with the least perfect conductors; the right-hand column commences with the least perfect conductors and ends with the most perfect :—

TABLE XXXII. *Electrical Conduction.*

CONDUCTORS.

Metals.
Charcoal, plumbago, &c.
Fused chlorides.
„ Iodides.
„ Salts.
Strong acids.
Alkaline solutions.
Water.
Alcohol.
Damp air.
Vegetable and animal bodies.

Spermaceti.
Glass.
Sulphur.
Fixed oils.
Spirits of turpentine.
Resins.
Ice.
Diamond.
Shell-lac.
Oxalate of lime.
Dry gases.

INSULATORS.

This distinction of bodies according to their conducting power regards them as *masses*; it is probable that the constituent particles, whether of conducting or non-conducting matter, are individually conductors, and capable, as such, of receiving a charge of electricity. In this distinction we are presented with a close analogy in the conduction of heat; for the particles of aëriform matter readily become heated, although heat travels amongst them by conduction with the greatest difficulty.

§ 303. The instantaneous way in which electricity passes along a good conductor, and the advantage which may be taken of the non-conducting power of bodies to prevent its escape from substances in which it may be required to confine it, may both be shown by a very simple experiment. Suspend a metallic wire of many yards in length by strings of white silk, from any convenient supports, and hang to one of its extremities two strips of gold leaf, so that they may be parallel to each other, and nearly in contact: present any excited body to the other extremity, and the slips of gold-leaf will instantly repel one another, and diverge; proving, whatever the length of the wire may be, that the influence is confined within its limits, and instantly pervades it from end to end. If the wire be now divided, and a connexion be made between its two ends by the smallest possible loop of silk, the electric fluid will be found incapable of passing through the interval of non-conducting substance. We thus make use of this difference in the conducting power of bodies for the purpose of *insulation*. By supporting good conducting substances upon non-conductors we can cause them to retain any electric charge which we may communicate to them; they thus become cut off or insulated from any ready channel by which the fluid might pass away, or attain to that state of equilibrium which it is always striving to effect. Without this power the electric forces could scarcely have been made the subjects of experimental investigation.

When a non-conducting substance becomes charged either by friction, or otherwise, with electricity, it will only partially give up the fluid on its surface to a non-insulated conductor at the point of contact; but a charged insulated conductor will instantly part with the whole of its charge. In the former case the fluid is supposed incapable of moving from point to point, while in the latter it will traverse any space in any direction without apparent obstruction.

If, again, a small charged conductor, such as a brass ball, be brought in contact with a smooth plate of resin, a portion of the electric fluid will adhere to the resin at the point where the two bodies touched, but will spread itself only to a very minute distance round.

§ 304. It was formerly supposed that the two great classes of conductors and non-conductors might be designated as *non-electrics* and *electrics*: the former name denoting a capacity of electric excitement, and the latter a total incapacity; but this distinction is quite inaccurate. If we hold a rod or tube of metal in our hand, and rub it with a silk handkerchief, it is quite true that it will exhibit no signs of excitation. The reason is, that both our bodies and the metal being good conductors, the electrical fluid passes away as it is disengaged; but if we insulate the metal,—cut it off, that is, from communication with the hand by means of a glass handle, —we shall find that upon friction it will become electrical, like the glass or the resin. The friction of two metals together, provided both be insulated, will excite electricity; and if we sift zinc filings through a copper sieve, provided with a glass handle, we shall find that the sieve and the filings will be oppositely excited.

§ 305. The mode of ascertaining the existence and nature of any electrical excitement is very simple. For this purpose we have recourse to a beautiful little instrument, called the gold-leaf electrometer. It consists of two slips of gold-leaf, suspended from a brass wire terminating in a small plate, within a cylinder of glass. The wire is insulated by the glass, and more effectually by passing it through a glass tube, covered with a varnish of shell-lac, and packed with silk. The leaves are made to diverge by contact with some body in a known state of excitement, as with a stick of sealing-wax rubbed with woollen; if the approach of the body, whose state we wish to determine, cause the leaves to diverge still more, we conclude that it is resinously electrical; if, on the contrary, they collapse upon its approach, it is a proof that it is in the vitreous state (67).

There is another mode which is still preferable to this, as affording not only an indication of the kind of force which is required to be tested, but also an accurate measure of its intensity. It consists of a needle of shell-lac, suspended from a fine thread of spun glass. At one extremity of the needle is placed a small disc of paper, or other conducting substance; which, being thus insulated, is capable of receiving and retaining a charge. When another electrified body is brought near to this, the kind of electricity which has been communicated to it being known, it will indicate by its attraction or repulsion, the species of electricity thus brought within its sphere of action; and the intensity of the force may be measured upon a scale by the amount of torsion in the thread which may be required to bring the two repelling bodies into mutual contact (68).

§ 306. Experiment has demonstrated that the same substance is not always similarly electrified by friction; but that its electrical state is determined partly by the condition of its own surface and

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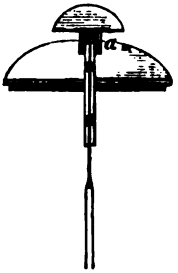
(67) Bennet's gold-leaf electrometer is here represented; the leaves being in a state of divergence from a charge which has been communicated to them.

The improved mode of insulation introduced by Mr. Singer is shown in the section *a*. The wire to which the gold leaves are attached passes through a glass tube packed with dry silk, and is covered by a brass cap, screwed to its upper end, by which it is protected from dust and damp.



(68) The following cut represents Coulomb's torsion-electrometer, or electrical balance. *a b* is a thread of silk or spun glass, from which the

partly by the body with which it is rubbed. Thus flint-glass with a smooth surface, when rubbed with woollen cloth, becomes vitreously electric; but if its surface be roughened, and it be rubbed with the same cloth, it will be resinously electrical.

Smooth glass, rubbed with every substance which has been tried, except the fur of an animal, as a cat-skin, becomes vitreous: with a cat-skin, resinous.
White silk rubbed with black silk, metals, or black cloth, is vitreous; rubbed with paper, or the hand, resinous.
Sealing-wax, rubbed with the metals, is vitreous; with cloth, paper, or the hand, resinous.

§ 307. It was first observed by Otto de Guericke, and Hawksbee, that the friction of glass and resinous substances not only produced the phenomena which we have just described, but, under favourable circumstances, was accompanied by a rustling or crackling noise; and, when the experiment was made in a dark room, by flashes and sparks of light upon their surfaces. When once the attention has been directed to the observation, most persons will find that such phenomena of electrical light are familiar occurrences, and often present themselves in suddenly drawing off from the person a silk stocking, or a flannel waistcoat, or in the friction of long hair, by combing. How small a degree of friction is sufficient to excite electricity in the human body, is shown in a striking way by placing a person upon an insulating stool with glass legs. If in such a position he place his finger upon a gold-leaf electrometer, and

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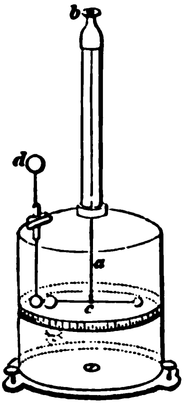
needle of shell-lac, *c*, is suspended. It is attached to the screw, *b*, by which it can be twisted round its axis. The needle carries a gilt ball of pith, or a disc of paper, at one extremity, which is balanced by a counterpoise at the other; *d* is a metallic wire passing through the glass shade, and terminated by a metallic ball at each end. The ball of the needle and the interior brass ball of the wire are brought into contact by turning the screw, *b*, and the index then points to 0 on the scale, which is marked upon the circumference of the glass.



another person flip him lightly with a silk handkerchief, the leaves will immediately repel each other.

§ 308. We may now proceed to describe the means of producing these effects upon a large scale, and the different modes which have been devised of exciting, collecting, and measuring the electric fluids.

The electrical machine, as it is called, whatever form it may assume, resolves itself into a more or less perfect way of applying to glass the friction of silk, or some other dissimilar substance, as in our fundamental experiment, and of drawing off the electricity as it is excited, and collecting it in a good insulated conductor. In machines of the more perfect construction, not only is the vitreous electricity collected in what is called the prime conductor, but the resinous also is accumulated by insulating the rubber, and connecting it with a metallic cylinder (69).

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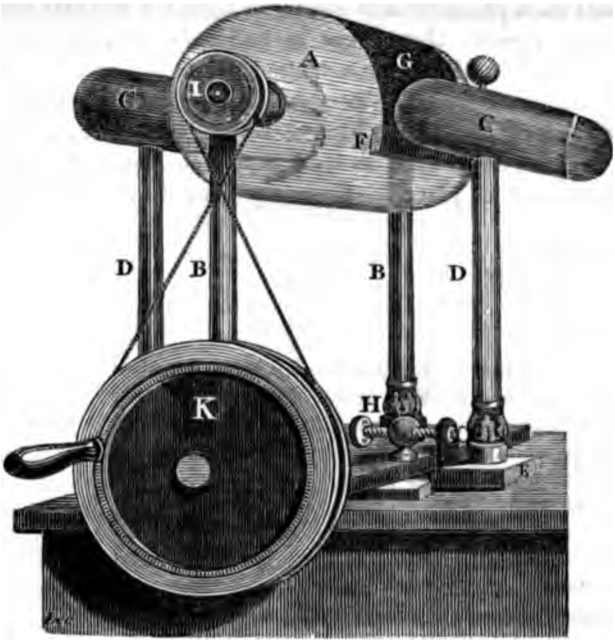
(69) This figure represents the cylinder electrical machine; A is a glass cylinder, properly mounted, to turn upon two stout glass pillars,



B B, strongly fixed upon a wooden frame. It is made to revolve rapidly, by means of the multiplying wheels, L and K. C C are two brass cylinders, Experience has shown that the most effective exciter of glass is a metallic substance; and when a soft amalgam of mercury, tin, and zinc, is spread upon the rubber, it forms a flexible metallic surface which is perfectly adapted to the purpose and greatly heightens the effect. The best proportions of the metals have been found to be one part of tin and two of zinc, fused together, and mixed whilst fluid with six parts of mercury. The mixture must then be triturated in a mortar, with a little lard, to the consistence of a thick paste. When large cylinders, or plates of glass, are made to rotate by convenient mechanical means, pressing against cushions covered with this metallic coating, they are capable of producing all the phenomena of attraction and repulsion in a high degree, and their state of intense excitement is accompanied by flashes and sparks of brilliant light, and a crackling sound (70).

When the prime conductor is placed in its proper position it receives from the glass, without contact with it, a charge in the form of a stream of fire, which, whatever may be the size of its surface, rises to nearly the same intensity as that of the original source; and which being thus acumulated in quantity will wholly pass off at once to any uninsulated conductor, or will instantaneously divide itself with an insulated one, by means of a dense spark. Similar phenomena may be obtained with the conductor attached to the rubber; but to obtain the highest effect from either, it is necessary to make a good conducting communication from the other to the ground. The reason of this is, that when the two electricities are in presence of each other they counteract and limit each others intensity: by connecting either conductor with the earth, its charge is spread over an indefinitely large surface, and virtually annihilated. That the two conductors are in opposite electrical states is easily proved by suspending from each some light substances which will strongly attract each other when charged: and that the two charges are

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supported upon the two glass pillars, D D, in a position parallel to the glass cylinder; to one of these a cushion, F, with a silk flap, G, is attached, which is made to press against the glass by a spring, its distance being capable of adjustment by means of the screw, H. The opposite brass cylinder has a row of points attached to it, to which the silk flap, G, extends. The latter goes by the name of the prime conductor, or the positive conductor; the former is distinguished as the negative conductor.

(70) The Plate Electrical Machine is figured in the next page. A is a circular glass plate, mounted upon a brass axis, and turning in a stout

exactly equal is shown by making a good metallic communication between the two, when all signs of excitement will cease in both.

§ 309. And now, it may be asked, where does the charge reside in a good insulated conductor? does it diffuse itself, like heat, throughout the whole of its substance? or is it confined merely to its surface? That it is merely superficial is susceptible of proof in several ways. If we take a solid globe of metal, and electrify it to a certain amount, and then bring it in contact for a moment with a globe of similar dimensions, made of the thinnest shell of the same metal, we shall find that the charge will distribute itself equally between the two. If we take a hollow sphere, with an aperture at its upper part, and having given it a charge of electricity, touch its interior with a small insulated ball, upon bringing this proof-ball in contact with an electroscope we shall find that it will afford no signs of having received a charge; but, on the

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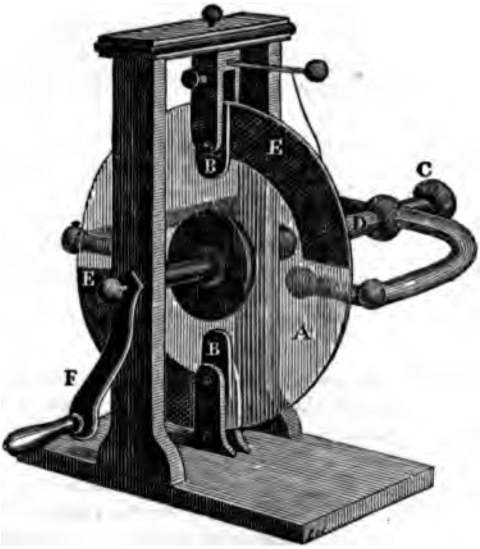
wooden frame, by means of the handle F; as it revolves it passes between two pair of cushions, B B, which are pressed lightly against it, by means of screws; C is the brass prime conductor, supported upon the stout glass arm, D; it is armed at its two extremities, which are opposed to the plate, with two rows of points which meet the ends of the two silk flaps, E E, which are attached to the cushions, B B.



contrary, if we touch the exterior of the sphere, it will carry away a part of the charge with it, and affect the instrument.

How much the intensity of the electric charge depends upon the surface may also be very elegantly shown by means of a metallic ribbon, coiled up by a spring, upon the top of a gold-leaf electrometer. When this apparatus is electrified the leaves, of course, repel one another in proportion to the charge which they receive. If the ribbon be now drawn out by a silk thread, or other insulating handle, the leaves will approach each other in proportion to the enlargement of the surface over which the electricity becomes diffused; and as it again coils itself up they will expand to their original amount. Here it is seen that the quantity of the charge remaining the same, its intensity decreases with the increase of the surface over which it is suffered to diffuse itself, and that the quantity of electricity which a given portion of matter may receive, depends upon the dimensions of its external surface.

§ 310. The next question which presents itself is, how does the electricity arrange itself around surfaces of different forms? in a layer of equal intensity in every part, or otherwise? This question is readily submitted to experiment, by means of a small insulated disc, which being applied to any part of the surface of an electrified conductor, becomes virtually a part of that conductor; and, upon being removed, carries with it a portion of the charge having the same intensity as that of the point to which it was applied, and which may be measured by the torsion electrometer.

In this way it has been proved that in the case of an electrified sphere, the intensity is the same at every part of the surface;—but this is the only form of surface upon which this equal distribution takes place. If two similar spheres be placed in contact with one another, it will be found that there are two points of greatest and equal intensity on their opposite sides, in a line with their points of contact where the force will be null. So in a cylinder, or bar of metal, the electrical intensity will be much greater at the two ends than in the middle, and this inequality of distribution will increase very rapidly in proportion to the diminution of the diameter of a cylinder of given length.

If two balls of unequal diameters be placed together, the maximum intensity of the extreme point of the smaller sphere will be higher than that of the corresponding point of the larger; and by adding a series of balls in contact with each other, all gradually decreasing in size, the intensity will increase upon the smaller as the diameter decreases. We can conceive a succession of such balls gradually diminishing till the series ends in a mere point, at which the electric tension will be at its maximum. In consequence of this law of distribution, a powerful dispersion of electricity takes place from all bodies of a pointed form; the intensity upon them increasing to such an extent that the surrounding insulating medium of air gives way before it, and no longer suffices to constrain it.

§ 311. Our attention has hitherto been directed to the electricity which is developed upon the surfaces of two dissimilar substances by mutual friction; or which has been transferred to other bodies from such excited substances by contact and direct communication. We have now to examine a remarkable influence which an electrified body exerts upon other bodies at such distances from it as prevent the direct transfer of any portion of the charge. The neutral state of an insulated conductor in its immediate vicinity will be destroyed. If it be in the form of a cylinder, furnished with electroscopes at each extremity and also at its centre, when one end is placed near the charged substance we shall find the two extreme electroscopes indicating electrical activity, while the centre remains quiescent. Upon slowly withdrawing the excited body, these secondary electrical signs gradually decrease, and finally disappear upon its complete removal or discharge. Upon examining, by the proof-plane and torsion electrometer, the kind of electricity developed by this distant influence, we shall find that the end of the cylinder, which is the nearest to the originally charged body, is in an opposite state to that body, and the furthest end in the same state; that the cylinder has, in fact, had a *polar state* communicated to it (§ 15). This distant action of an electrified body, by which its own charge is in no degree lessened, is distinguished by the name of *induction:* the secondary state of the neighbouring body is called *induced electricity:* and the body itself is said to be under induction. Further, the originally active body is conveniently distinguished as the *inductric* or *inductive* body, and that under its influence, as the *inducteous* body (71).

§ 312. If, whilst in a state of electric induction, that end of the cylinder which is most remote from the inductric body, have its electricity discharged by a momentary contact with an uninsulated conductor, upon removal of the inductric body, or its discharge, the cylinder will be found to be permanently electrified with the contrary electricity: or if the cylinder be divisible into two at its centre, and while under induction the opposite ends be separated from each other, one will be found permanently electrified vitreously, and the other resinously, upon removal from the influence of the originally charged body. In the theoretical language of Du Fay's hypothesis, the fluid of opposite name to that of the originally excited body is drawn to that extremity of the cylinder which is the nearest to it, while that of the contrary name is repelled to the greatest distance. When the latter is withdrawn, and the induction destroyed, it cannot return to neutralize the former, which consequently remains in an active state.

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(71) Let *a* represent an electrified ball, and *b c* an insulated metallic cylinder, near it, the feather attached to the end, *b*, will be attracted, and show that it is in an opposite state to that of the charged

This polar state may be excited in a long series of insulated conductors, by induction; the intensity, however, of the forces decreasing rapidly as the distance from the originally charged body increases. Throughout the system the vitreous pole, or end, of one will be opposed to the resinous pole of another and the intensity of all will rise by connecting the last with the ground.

§ 313. Having thus distinguished these different kinds of action into which electricity has been conventionally subdivided, we may now proceed to examine more closely the mechanism of the phenomena; for an explanation of which we are wholly indebted to the recent researches of Dr. Faraday. Up to the date of his discovery, the phenomena of induced electricity were supposed to arise from an action of a charged body upon others at a distance, in straight lines, through non-conducting media; the particles

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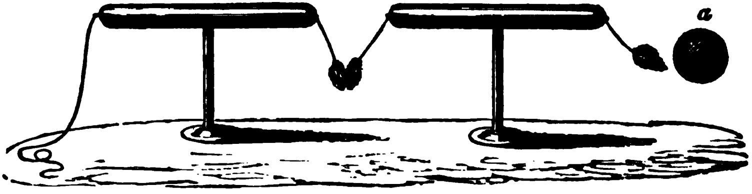
ball. If *d e* be a second insulated cylinder, placed near the first, it will also show signs of electrical charge, and the extremity, *d*, will be in an opposite state to end, *c*, of the first cylinder, for the feather attached to



the two will attract each other. Upon removing the ball, *a*, from the vicinity of the first cylinder, or upon discharging it, all signs of electricity in the two cylinders will disappear.

of which were assumed to be unaffected by it. He has shown induction, on the contrary, to be an action of contiguous particles throughout, capable of propagation in curved lines, and to be concerned in all electrical phenomena; having in reality the character of a first essential, and fundamental principle.

§ 314. We have seen that one electric force cannot be produced without an exactly equal development of the other; and upon more attentive examination we shall find that no kind of matter, either conducting or non-conducting, is capable of receiving a charge in any way of one kind of electricity independently of the other, or without calling forth an equal amount of the opposite force in adjacent bodies. It was formerly supposed that the electric fluid was confined to the surfaces of bodies by the mechanical pressure of the non-conducting air, in the midst of which all our experiments are carried on; but the fact is, that the electric force originating or appearing at a certain place, is propagated to, and sustained at, a distance, through the intervention of the contiguous particles of the air, each of which becomes polarized as in the case of insulated conducting masses, and appears in the inducteous body as a force of the same kind exactly equal in amount, but opposite in its direction and tendencies.

Such a forced arrangement of the molecules cannot be made to appear to the eye in the case of the air, but is established by the most perfect inductive reasoning; and a similar disposition may actually be exhibited by substituting a liquid non-conductor for the air under similar circumstances. If we take a tall, wide-mouthed glass vessel, and place it upon the prime-conducter of the electrical machine, taking care that there may be a good metallic communication through its bottom, and then fill it with spirit of turpentine containing some threads of white silk about one-eighth of an inch in length disseminated through it, they will be little affected upon turning the machine till a metallic conductor is held near the surface of the liquid. Upon presenting, however, such a body, they will immediately erect themselves, and collecting from all parts, will attach themselves to each other end to end, and form a continuous chain from the conductor to the exterior metal, towards which they will always incline as it is moved in different directions. These particles will adhere together with considerable force, as may be felt by touching them with a rod of glass; but the moment the conductor is discharged, they fall upon their sides, and sink to the bottom.

Now these solid threads of silk accurately represent the fluid particles of the spirit in which they float, or of the air which is interposed between a charged conductor and surrounding bodies, and obviously assume a polar state, exactly resembling that of insulated conductors in similar circumstances (72). If, instead of silk threads, we occasion particles of gold-leaf to float in the spirit of turpentine, there semblance will be perfect; for, on approaching them with a rod of metal, when the conductor is charged, they immedi-

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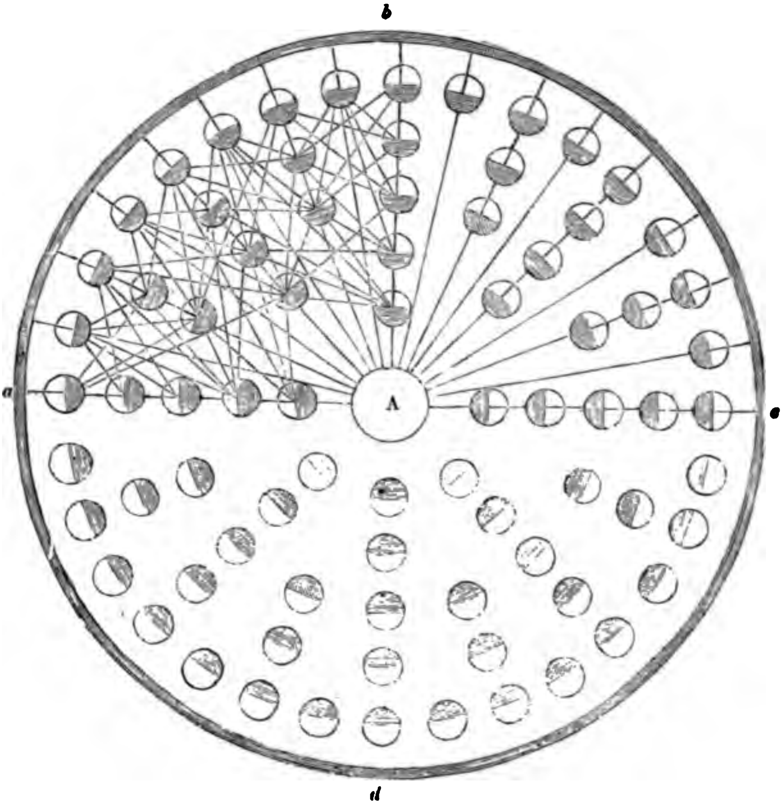
(72) In the annexed diagram, let A represent an insulated electrified ball placed within an uninsulated metallic sphere, *a b c d*, filled with a non-conducting medium, whose particles are represented by the small included circles. These will be all thrown into a polar state, indicated by the shading, resembling the silk particles in the spirit of turpentine: their dissimilar poles will be all turned towards the ball A, and in this way their combined influence will be thrown upon the metallic sphere, *a b c d*, which will thus have a force of the opposite kind to that upon A, developed upon it, of exactly equal amount, but diffused over the larger surface. It is conceived that the polarized particles are capable of affecting each other, not only in straight lines as in the quadrant A *b c*, but in lines diverging from their centres, as shown in the quadrant A *b a*.



ately start on end as if endued with life, assume the polar state, attract each other end to end, but owing to their perfect conduction, discharge their electricity by minute sparks.

Each polarized particle is in active relation, not only to a line of particles in some definite direction from it, but to all those which are contiguous to it. Hence, there is a lateral diffusion of force, and the lines of inductive action, when unobstructed, tend to spread as from a centre; or may assume a curved direction when any obstacle opposes their free radiation (73).

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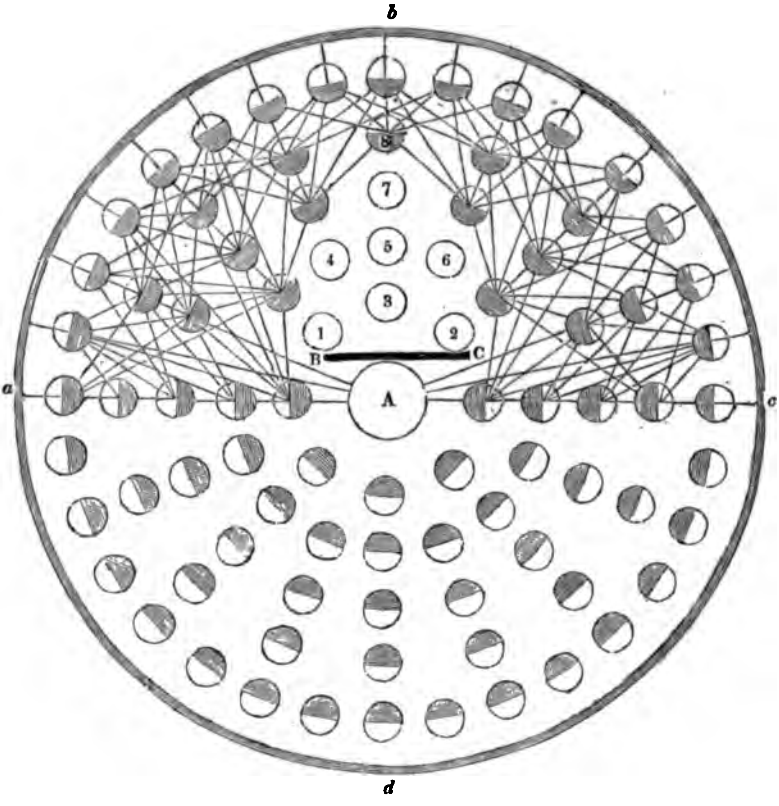
(73) In consequence of the lateral action of the particles upon one another, if B C be an obstacle interposed in the course of the induction from A to *a b c d*, the particles 1 2 3 4 5 6 7 will be protected from the influence, but the induction will affect the particle 8, by the bending of the lines of force on each side of it.



The particles 1 2 3 4 5 6 7 themselves, although here represented in their natural state, will be affected by a reflex action; but will be polarized to a much lower degree than those within the influence of the direct action.

§ 315. The reason of the residence of all the electricity upon the exterior surface of a charged body, and of the influence of the form of the body upon its distribution, will readily appear from considering this inductive process. No charge can be sustained in the interior of the globe in which we sought it in a previous experiment (§ 309), in consequence of opposing actions in different directions (74); but if, instead of touching it with a small insulated ball which brought away no electricity with it, we touch it with an insulated rod, a part of which projects beyond the sphere, a charge will be obtained.

Dr. Faraday constructed an insulated cubic room of twelve feet in the side, into which he went with all his apparatus of lighted candles, electrometers, and all other tests of electrical states, and could find no influence upon them, although the room itself was highly charged by a powerful electric-machine, and large sparks and brushes were darting off from every part of its outer surface.

The arrangement which strips of conducting substances tied together and electrified at one end assume, indicate very clearly the direction of the lines of induction, and the influence of surrounding objects. Strips of paper placed upon a long rod in connexion with the prime-conductor of the machine, in the centre of a large apartment, will open out equally like radii from the centre of a sphere; but if any conducting body be approximated to them in their charged state, they will incline towards it from the concentration of the force upon its nearer surface (75).

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(74) Thus, referring back to Fig. 72, if we suppose *a b c d* to be a hollow sphere charged with electricity, an insulated ball, A, introduced into it, and touching it in any part, could receive no charge, because being surrounded by a surface in one electric condition, it could not induce the opposite state by polarizing the surrounding air, by which alone a charge could be sustained. This will be obvious at once, by supposing the ball, A, shaded the same as the circle, *a b c d*, to denote a similar state of electricity, when the polarized state of the particles represented in the diagram would be seen to be impossible.

(75) This is illustrated by the ridiculous figure of the *head of hair*, which is a common electrical experiment. When electrified, the hair stands on end; and each fibre, as if in a state of repulsion from its neighbour, is attracted by, and radiates towards, the point which is nearest to it in the oppositely induced state.

Even the prime-conductor of the electrical machine itself may be of such a construction as to afford proofs of no electrical charge upon some portions of its surface, while strong sparks may be drawn from others. If we place eight or ten metallic rods upon it, each terminated with a ball, and all diverging from one common centre, strong sparks may be drawn from each extremity while the surfaces of any of the interior rods of the group may be tested with the proof-plane, and will give no indications of charge.

§ 316. The known influence of simple form to which we have already referred (§ 310), is perfectly consistent with the new corpuscular view of induction. An electrified cylinder is more affected by the influence of the surrounding conductors (which are necessary to its charge) at the ends than the middle, because the ends are exposed to a greater sum of inductive forces than the middle; and a point is brought to a higher condition than a ball, because by relation to the conductors around, more inductive force terminates upon its surface than on an equal surface of the ball with which it is compared (76).

§ 317. Induction requires no sensible thickness in the conductors which may be used to limit its extent; an uninsulated leaf of gold may be made very highly vitreous on one side, and as highly resinous on the other, without the least interference of the two states whilst the inductions continue. But with regard to the insulating media, their thickness has an immediate and important influence on the degree of induction. There is perhaps no distance so great that induction cannot take place through it; but with the same original charge or constraining force, it takes place the more easily according as the extent of the medium through which it is exerted is lessened. The particles of the latter, though thrown into a forced condition during the action, tend to return to a normal state; and the fewer there are exerting this tendency, the higher will be the condition they assume, and the larger the amount of inductive action exerted through them.

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(76) Our comprehension of this statement may perhaps be assisted by again referring to Fig. 72. The charge of the ball, A, as we have already explained, is sustained by induction, and the contrary state of the surrounding sphere, *a b c d*. If, instead of the ball A, we imagine a point to be introduced, it will be obvious that all the lines of force indicated by the polarized particles, which were disturbed over the surface of the ball, would be concentrated upon the point, and that consequently the latter might rise to a higher degree of intensity than the former.

§ 318. If an insulated brass-plate be connected with a gold-leaf electrometer, a charge of electricity may be communicated to it which will be sustained in consequence of induction through the air towards distant surrounding objects, and its intensity will be indicated by the divergence of the leaves: this divergence, it being now understood, not arising from any self-repulsive property, but from the attraction in opposite directions of the oppositely electrified inducteous bodies uncompensated by any attraction between themselves. When in this state, if another equal plate, also insulated, be opposed to it, as it is made to approximate to it the leaves of the electrometer will fall; the process of induction being directed almost wholly through the thin intervening stratum of air to the nearer body, which will itself be in the polar state. If the second plate be now uninsulated by connecting it with the ground, the leaves will still further collapse as the electricity of the same kind with that of the inductric body will be virtually annihilated by diffusion over the indefinitely large surface of the earth. When the second plate is again withdrawn, the leaves will reopen to their former extent, indicating that the inductive process has resumed its former direction.

§ 319. The inductric plate, whilst under the influence of the second plate, is capable of receiving a higher charge of electricity, and the leaves of the electrometer may be made to open out to the same amount as in the absence of the latter; for the charge will not only be sustained by the inducteous plate, but also by surrounding objects as before it was placed in its position. When, under these circumstances, the second plate is again removed: the accumulation which has been effected will be indicated by an expansion of the leaves far beyond their original amount, the whole being now thrown upon the surrounding conductors.

This is the principle of the action of an instrument which has been called the *condenser*, by which small quantities of electricity may be accumulated and rendered apparent (77).

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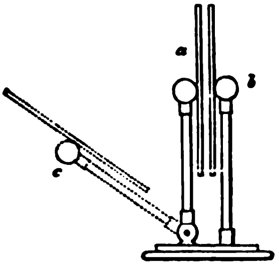
(77) One form of the condenser is exhibited in this figure, in section: *b* is a brass plate supported upon a glass stem; *a* is another brass plate of the same size as the former, capable of being placed as close to it as possible without touching. It is supported by a brass stem, which moves upon a hinge joint: it is shown in a second position at *c*.



§ 320. The attraction of bodies free to move, by others in an electrified state, is in all cases owing to the previous development of the opposite condition by induction. This is beautifully shown in an arrangement of Mr. S. Harris, in which a circular plate of gilded wood is suspended by insulating threads from one of the arms of a delicate balance, and counterpoised. Upon its upper surface is fixed, by a hinge-joint, a small lever of straw terminating in a pith-ball. When a similar plate charged is brought under this suspended plate, the pith-ball indicates by its repulsion the inducteous state which precedes the descent of the plate from the attractive force. When they come in contact, the original charge is divided between the two plates, and mutual repulsion appears to take place. This apparent repulsion again is dependent upon the attraction of each in opposite directions, by the inductric action which it exerts upon surrounding bodies.

A pith-ball, or other light substance, placed upon a conducting surface under an electrified plate, is rendered inducteous, and drawn upwards; but when it comes in contact with the plate its inducteous state is destroyed, it is charged with similar electricity, and becoming inductric, it is attracted downwards, and parts with its charge.

In a similar way induction always precedes charge in insulated conductors, and the prime-conductor of the machine has the resinous state strongly elicited upon its points previously to its becoming charged with the vitreous electricity of the excited glass.

§ 321. There is another instrument of electrical research, called the *electrophorus*, which is well calculated to illustrate several

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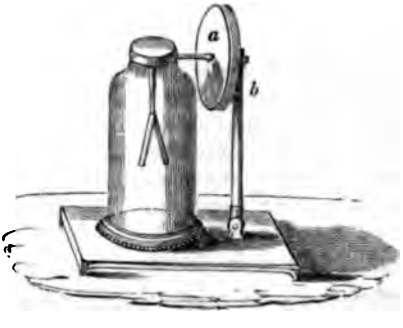
A condenser, similar to that in the preceding figure, is here shown in connexion with a gold-leaf electrometer.



interesting points of the process of induction. It consists of a plate of resinous matter about half an inch thick, placed upon a plate of metal. A second polished metal plate of rather smaller diameter, is fitted with a glass insulating handle, by which it can be lifted on or off the upper surface of the plate of resin. When the resin has been excited by gentle friction with dry fur or flannel, and the plate placed upon it by its handle, and immediately removed, it will be found to have received a very feeble charge of resinous electricity by contact. If it be then replaced and uninsulated by contact with the finger or a metallic rod, and again lifted by its insulating handle, it will be found to give a strong spark of vitreous electricity. This process may be repeated an unlimited number of times without requiring any fresh excitation of the plate, which circumstance, as well as the opposite nature of the charge, shows that the electricity of the moveable plate is not derived in the way of charge from the resin, but is the result of the process of induction. The metallic plate cannot, in fact, be considered in absolute contact with the resinous, owing to the inequalities of the surface of the latter: the former, therefore, is precisely in the state of a conductor opposed to, but not touching, an electrified surface; and therefore capable of being rendered electrical by induction, when uninsulated by contact of the finger. As the resin loses but little of its acquired charge by each contact, the instrument is capable of being used as a permanent source of electricity always at command, and in a dry atmosphere will remain in action for many successive months (78).

§ 322. When the electrophorus is placed upon an insulating stand, its lower plate is always found in an opposite state to the upper one; proving that the friction of the upper surface communicates a polar state to all the particles of the resin which penetrates even through its mass. This charge it is necessary to remove by contact with an insulated substance, to give full effect to the opposite charge upon the upper plate.

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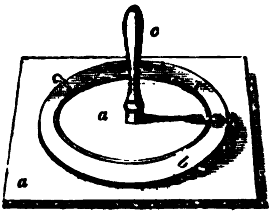
(78) This figure represents the electrophorus. *a a* are two metallic plates, and *b* a plate of resinous matter. The upper metallic plate has an insulating handle, *c*, by which it can be lifted from its position, and replaced.



§ 323. It was by an apparatus constructed upon similar principles that Dr. Faraday brought to the test of experiment his theoretical anticipation that, inductive action taking place invariably through the intermediate influence of intervening matter, would be found to be exerted, not in the direction of straight lines only, as had always been assumed, but also in curved lines. A cylinder of solid shell-lac of about an inch in diameter and seven inches in length, was fixed in a wooden foot; it was made concave, or cupped, at its upper extremity, so that a brass ball, or hemisphere, could stand upon it. The upper half of the stem having been excited resinously by friction with warm flannel, a brass ball was placed upon the top, and then the whole arrangement examined by the carrier ball and Coulomb's electrometer.

For this purpose the carrier was applied to various parts of the ball, the two were uninsulated whilst in contact, or in position, then insulated, separated, and the charge of the carrier examined, as to its nature and force. Of course whatever general state the carrier acquired in any place where it was uninsulated, and then insulated, it retained on removal from that place, and the distribution of the force upon the surface of the *inducteous* body while under the influence of the *inductric* was ascertained. The charges taken from the ball in this, its uninsulated state, were always vitreous, or of the contrary character to the electricity of the lac. When the contact was made at the under part of the ball, the measured degree of force was 512°; when in a line with its equator, 270°; and when on the top of the ball, 130°.

Now, the first two charges were of such a nature as might be expected from an inductive action in straight lines; but the last was clearly an action of induction in a curved line; for during no part of the process could the carrier-ball be connected by a straight line with any part of the excited and inducing shell-lac. To render the experiment still more decisive, the carrier-ball was not placed in contact with the larger ball at all, but a little above it; when, having been uninsulated, insulated, and afterwards examined, it was found charged vitreously, and even to a higher degree than when it had been in contact (79).

§ 324. If instead of the ball a disc or hemisphere of metal, of two inches diameter, be used, no charge will be given to the carrier when placed on its centre; but when placed considerably above the same spot, a charge will be obtained; and this even if the plate be merely a thin film of gold leaf. Hence it is clear that the induction is not through the metal, but through the air, and that in curved lines, by which it turns the corner of the plate. The course of the inductric action may thus be disturbed from its rectilineal direction by the shape and position of the metallic plate; and the lines of direction will assume a curved form in consequence of their lateral tension on one another; all depending, as Dr. Faraday conceives, on induction being an action of the contiguous particles of the insulating body, thrown into a state of polarity and tension, and capable of communicating their forces in all directions (80).

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(79) The shell-lac electrophorus, with the brass ball upon its summit, is here exhibited, together with the positions of the carrier-

When uninsulated conducting matter was brought near to the excited shell-lac stem, the inductive force was directed towards it, and could not be found on the top of the plate. The lateral ten-

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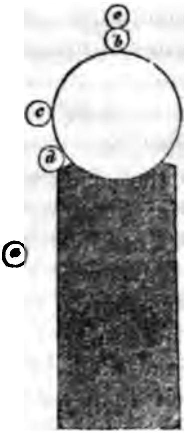
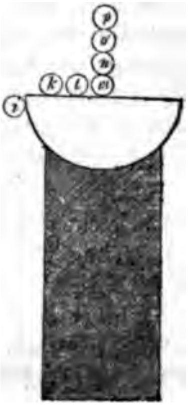
ball, referred to in the text. When placed at *d*, the effect produced was 512°; at *c*, 270°; at *b*, 130°. Even in the position *e*, the proof ball became inducteous, and at *a* it was effected in the highest degree, and gave a result above 1000°.



(80) When the carrier-ball was placed in the respective positions delineated in the figure at *i*, the force was 112°; at *k*, 108°; at *l*, 65°, at *m*, 35°; the inductive force gradually diminishing to this point. But on raising the carrier to the position, *n*, the charge increased to 87°, and on raising it still higher, to *o*, it still further increased to 105°. At a higher point still, *p*, the charge decreased to 98°, and continued to diminish for more elevated positions.

The analogy between these experimental results, and the theoretical deductions represented in Fig. 73, will be at once perceived.



sion, or mutual repulsion, of the lines, was so much lessened, that no inducteous charge could be given to the carrier-ball in that position; but upon removing the matter, the lines of force resumed their former direction.

§ 325. The phenomena of induction, which we have been examining, we have considered principally as produced by the intervention of the aërial molecules of our atmosphere: we must now enter upon a closer investigation of the inductive properties of other insulating media. We have already found that liquid oil of turpentine is capable of undergoing the same polarization of particles; and we have had reason to conclude from one of the properties of the electrophorus, that resinous solids are susceptible of the same forced arrangement under the influence of an excited charge. All insulating substances, or substances which are capable of this peculiar development of the two opposite electrical forces, whether solid, liquid, or aëriform, Dr. Faraday classes together under the name of *dielectrics.*

§ 326. We have seen (§ 319) that by approximating a metallic plate to a charged conductor, so as to leave an intervening portion of air, the conductor is capable of receiving a higher charge, and the air of assuming a higher polar tension, than when the charge is sustained by distant objects in ordinary circumstances. The tension increases with the thinness of the aërial stratum, and is in inverse proportion to the squares of the distances of the two plates. It is necessary to the attainment of the maximum effect that the second plate be uninsulated; that is to say, that it be prevented itself from assuming the polar state by the annihilation of its remoter associate force, by the reaction of which the induction would otherwise be limited: or, more accurately speaking, by allowing it to diffuse itself over the indefinitely large surface of the earth, thereby proportionately lowering its tension. The rise of the force, under these circumstances, is ultimately limited by the mobility of the particles of the air, in consequence of which the equilibrium is restored either silently or in the form of a spark.

But if a solid dielectric be substituted for the air, the state of tension is capable of rising to a degree limited only by its cohesive force. Thus, if a plate of glass be coated on both sides with tinfoil, within an inch or two of its edge all round, and one side be placed in connexion with the prime conductor of the electrical machine, we shall have an exactly similar arrangement to that of the two plates of the condenser, with its interposed stratum of air.

Upon connecting the opposite coating with the ground to destroy its polar state, the particles of the glass are forced into a polarized or constrained condition by the electricity of the charging apparatus; which is sustained till the return of these particles to their natural state from their state of tension, whenever the two electric forces are allowed to neutralize themselves by some other channel, as by the interposition of a good conducting body between the coatings. The quantity of force which may be thus accumulated may, in some degree, be estimated by the number of turns which it may be necessary to give the machine before the intensity, as measured by the electrometer, rises to the same degree as that which is almost instantaneously communicated to the conductor, when the charge is sustained alone by the inductive medium of the air to surrounding objects, and will be found to be in proportion to the coated surface of the glass (81).

§ 327. There is no difficulty in perceiving that the opposite surfaces of the dielectric and conductors may be arranged in different forms without impairing the effects; and experience has proved that coated jars or bottles are the most convenient for extensive apparatus of this condensing kind. The honour of the discovery of the means of accumulating electricity is generally given to a Dutch philosopher, of the name of Muschenbroek, who resided at Leyden, and hence the name of the Leyden jar, by which the arrangement is commonly known. He instituted some experiments for the purpose of ascertaining whether a greater charge might not be given to electrified bodies, by surrounding them with more perfect non-conductors than the air; and with this view he attempted to charge some water contained in a glass vessel. An iron nail passed through a cork, and communicated with the water in a phial, which was grasped in the hand. After holding the nail for some time in contact with the prime conductor of the machine, he attempted to remove it with the other hand, and experienced a violent concussion in the arms, and across the breast. This experiment soon became popular, and the sensation it produced was called the electric shock.

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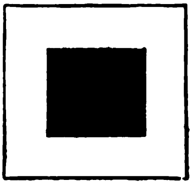
(81) A plate of glass is here represented with a coating of tin-foil, to which a similar one on the opposite side corresponds.



The first experimenters gave ludicrous and exaggerated accounts of its effects, which served to excite curiosity to a very high degree; and in the very year of its discovery it was shown by itinerant exhibiters in every part of Europe. The principles upon which this accumulation or power depended were not of course understood; but it is now obvious that the water in the phial, and the hand which grasped it, acted, although more imperfectly, as the two coatings of the glass. When the nail was touched with the other hand, a good conducting communication with the two surfaces was opened, by means of the fluids of the body through which the tension and polarity of the forces were destroyed (82).

The *quantity* of electricity which may be accumulated in a Leyden jar depends upon the extent of its coated surface; its *intensity*, upon the thinness of the glass.

§ 328. When large quantities of electricity are required for experiment it is found more convenient in general to employ several jars instead of one; and a number of jars arranged together, with their internal and external coatings respectively in metallic communication, is called an *electrical battery*.

In practice it is found impossible to diminish the thickness of the glass beyond a certain extent; for the constrained position of its polarized particles becomes at length so extreme that the cohesive force itself gives way, and the charge passes with violence through a hole, which it pierces for itself in the weakest part of the plate.

§ 329. A method has already been indicated (§ 326) of roughly estimating the quantity of electricity in a charge, by the number of turns of the electrical machine. Its intensity may be approximatively determined by the amount of repulsion between any two moveable bodies under its influence; or rather by the amount of their opposite attractions by surrounding bodies under their induc-

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(82) This is the usual form of the Leyden jar. The interior coating reaches up to nearly the same height as the exterior, and is in metallic communication with the brass ball, by means of a wire passing down to the bottom.

tive influence. An instrument was contrived by Henley, for measuring this effect upon the graduated arc of a circle (83).

§ 330. But we are indebted to Mr. Snow Harris for an accurate instrument for ascertaining this important point, founded upon the following principles.

From what has preceded, it will be obvious, that if a Leyden jar be insulated it will be incapable of receiving a charge of any considerable amount. In proportion as the vitreous electricity is communicated to its interior coating, it is necessary that the same quantity should be removed from the exterior, which would otherwise counteract the resinous electricity by which the charge is sustained. This may be effected by connecting it with the ground, or with the coating of another jar, which will thus also become charged, provided its exterior coating be uninsulated. A long series of insulated jars may thus be charged from each other, provided the opposing electricity of the last be withdrawn: and we thus obtain a polar arrangement through glass, of a precisely similar nature to that which we formerly obtained through air, but of a much higher degree of intensity (84).

If a very small jar be thus connected with a large one, the quantity of electricity which is sufficient to carry the charge of the first up to a high degree of intensity, when diffused over the larger surface of the second, will scarcely be appreciable; so that it will require many charges of the former to charge the latter to the same degree. This is the principle of Mr. Harris's *unit jar*. Instead of transmitting the electricity evolved by the machine immediately from its conductor to a large jar or battery, he communicates the charge from the outer coating of a small jar, furnished with a discharging-rod, by which the distance between its two coatings may be regulated and measured; and by the number of explosions, that is to say, by the number of charges which have passed from the

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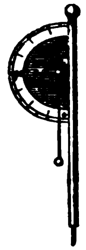
(83) The Quadrant Electrometer is here represented. It is screwed upon the jar, or battery, whose charge it is intended to indicate; and as it increases, the light index, composed of a straw terminated by a pith-ball, moves from its centre of suspension, and measures the intensity upon the graduated semicircle.



(84) Let *b* (in the figure overleaf) be a Leyden jar, standing upon the glass support, *a*. It will receive no charge from the prime conductor,

smaller jar, the quantity accumulated in the battery may be very accurately estimated. By diminishing or increasing the distance between the discharging surfaces, the value of the unit may be varied at pleasure (85).

§ 331. In the usual construction of the Leyden jar, or battery, the stem or wire by which the charge is communicated to the interior coating is left attached to it; the consequence is, that the induction does not take place solely through the glass to the opposite coating, but is partly directed through the air to surrounding conductors; this portion has commonly been called *free charge*. It is only, however, so far free as that it is not supported by the particles of the glass between the metallic coatings, but by those

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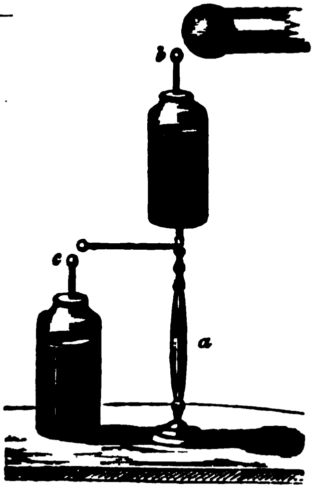
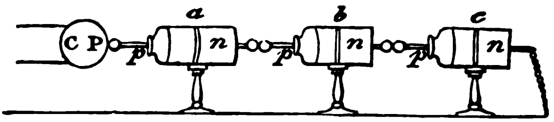
unless a conducting communication be made with its outside coating and the earth. If an uninsulated second jar be placed at *c*, the electricity which passes off from the outside coating of *b*, will charge *c*, and for every spark which passes from the prime conductor to *b*, a similar one will pass from *b* to *c*.



A polar arrangement of three jars is here shown, in which the extremity, P, of the prime conductor is positively electrified. The balls, *p p p*, connected with the interior coatings of the jars, *a b c*, are also positive, and the exterior coatings, *n n n*, the last of which discharges its positive electricity to the ground, are negative: or, it should be rather said, that the opposite surfaces of the glass with which they are respectively in contact, are in these opposite states.



(85) The Unit Jar is represented on next page, mounted upon an insulating stand, *f*. A communication is made with the prime conductor

of the air intervening between one coating and surrounding objects. When a charged jar is insulated, this free charge may be removed from the interior, by contact with a conducting body; when a corresponding portion of free charge of the opposite kind will make its appearance upon the outside coating, owing to the induction which will now be at liberty to direct itself from that part to surrounding objects. By successive alternate contacts, the whole of the charge may ultimately be removed, and the glass return to its natural condition.

The exterior conducting communication may be so contrived that it may be removed after the charge has been communicated, and then the induction will be determined entirely through the glass, and the charge on one side will be sustained by an exactly equal quantity of the contrary electricity on the other. All interference of surrounding objects being thus cut off, the jar will retain its charge for an indefinite period.

§ 332. That the charge of the Leyden jar is dependent entirely upon the dielectric glass, and not upon the conducting coatings, is proved by constructing a jar with moveable conductors. If such an apparatus be charged the interior lining may be lifted out by an insulating handle, and the jar itself raised from its exterior metallic case, and still the charge will remain. In this case the superficial rows of particles on both sides of the dielectric become charged by the intervention of the metal plates, and retain that charge after they are removed; those on one side being in the opposite state to those on the other, and the intermediate particles

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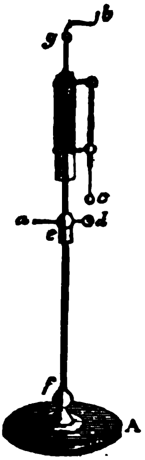
of the machine, and the exterior coating by the wire, *g b*, and the interior coating is connected with the interior coating of the jar to be charged by the wire, *a d*. The value of the unit of measure is determined by the distance between the balls, *c* and *d*, or the striking-distance of the spark. The effect of a spark from *c* to *d* is to neutralize the coatings of the unit jar, and to distribute a corresponding quantity of electricity over the surface of the large jar. On giving a second charge to the unit jar, the large jar receives an increment equal to what it received from the first charge, and the second spark only neutralizes the charge of the unit jar, as before, &c.



in a polar state. The only use of the coatings is to furnish a ready means of communication between the charged particles, by which the opposite forces may be neutralized at the same moment when the circuit is completed between them. Without the coatings the jar may be discharged, as it were, piecemeal; but upon replacing them, the discharge will take place in the usual instantaneous way.

Neither are the coatings absolutely necessary to the charge of a glass plate. If a clean dry glass jar be held over an electrified metallic rod, the point of which is brought opposite different parts of its surface, it will become charged, and if metallic coatings be then applied, it may be discharged at once; or if it be placed upon a metallic plate, over some pith-balls, or other light substances, they will be attracted and repelled backwards and forwards, and effect the discharge of the electricity, which induces from the interior towards the plate. They will then remain at rest; but if the electricity which has now been disengaged upon the outside towards surrounding objects be removed by a touch of the hand, a fresh portion will be set free on the interior, and the attraction and repulsion of the balls will again take place; and thus for many times successively the action will be renewed, until the glass returns to its natural state (86).

§ 333. From the peculiar view which he had taken of the phenomena of induction, Dr. Faraday was led to expect some particular relation of the process to the different kinds of matter through which it might be exerted, or something equivalent to a *specific electric induction* for different bodies. This relation he succeeded in establishing by the most decisive experiments. He examined carefully inductive action when taking place through different media, by means of an apparatus, consisting of two metallic spheres of unequal diameter, placed the smaller within the larger, and concentric with it. The interval between the two, being the space through which the induction was to take place, could be filled with

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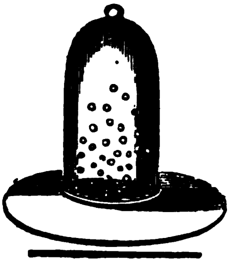


(86) An electrified bell-jar is here represented, placed upon a metallic plate, and the pith-balls in their state of alternate attraction and repulsion.

either solids or liquids, and, by previous exhaustion by the air-pump, with aëriform matter, which could be retained between the surfaces for any length of time. The interior ball was supported in its place by a stem, carefully covered with shell-lac, and passing through a collar fixed to the upper hemisphere of the exterior sphere. The inductive apparatus was, in fact, a Leyden phial, with the advantage of permitting the dielectric, or insulating medium, to be changed at pleasure. By peculiar and delicate manipulation, definite charges of electricity were communicated to this Leyden apparatus, and the aptness or capacity of different media for induction was ascertained by means of a Coulomb's electrometer and carrier ball.

The question to be resolved may be stated thus:—suppose an electrified plate of metal (A) insulated in the air, and B and C, two exactly similar plates placed parallel to, and on each side of A at equal distances and uninsulated; A will then induce equally towards B and C. If in this position of the plates, some other dielectric than air, as shell-lac, be introduced between A and C, will the induction between them remain the same? Will the relation of C and B to A be unaltered, notwithstanding the difference of the dielectrics between them?

These simple conditions of the experiment were afterwards combined by Dr. Faraday, in an instrument which he has called a differential inductometer; which consists of three insulated metallic plates placed as above suggested; each exterior one being connected with an insulated gold leaf of an electrometer. When a charge is communicated to the centre plate under ordinary circumstances, the induction is equal on both sides, and the gold leaves are not affected; but if a thick plate of shell-lac be interposed between two of the plates, unequal induction will take place on the two sides, and the gold leaves will attract one another. The final result which Dr. Faraday obtained may thus be stated:—

Specific inductive	capacity of	Air . . .	1
”	”	Glass . . .	1.76
”	”	Shell-lac . .	2
”	”	Sulphur . . .	2.24

The results obtained with spermaceti, oil of turpentine, and naphtha, were not in opposition to the conclusion that their inductive capacities were higher than that of air, but their conducting powers interfered with the result.

With regard to aëriform matter, one most striking result came out; namely, that all had the same power of, or capacity for, sustaining induction, and that no variations in their density or elasticity produced variation in the electric tension, until the rarefaction was such that discharge could take place across them. Hot and cold air were compared together, also damp and dry air, but no difference was found in the results.

§ 334. During these experiments upon the different inductive capacities of different bodies, the curious fact was established, that an actual penetration of the charge to some distance within the dielectric, took place at each of its two surfaces, by what is called conduction; so that the electric forces sustaining the induction, are not upon the metallic surfaces only, as has just been stated, (§ 332), but upon and within the dielectric also. Let a plate of any dielectric be armed in the usual way with metallic coatings, and a vitreous charge be communicated to one, while the other is uninsulated, and let the whole remain from ten to fifteen minutes. If then the coatings be discharged, insulated and immediately examined, no electricity will be found in them; but in a short time, upon a second examination, they will appear charged in the same way, though not to the same degree, as they were at first. A portion of the vitreous force, under the coercing influence of all the forces concerned, penetrates the dielectric, and takes up its place a little within its surface; a corresponding portion of the resinous force also assuming a similar position on the opposite surface. The discharge destroys or neutralizes all external induction, and the coatings are therefore found unelectrified; but it also removes almost the whole of the forces by which the electric charge was driven into the dielectric, and it therefore returns on its course to the surfaces, and constitutes the re-charge observed.

Two plates of spermaceti (a substance whose insulating powers are not very perfect) were put together so as to form one plate, and coated with metal in the usual way. The system was charged, then discharged, insulated, examined, and found to give no indications of electricity. The plates were then separated from each other, and one was found in the vitreous, and the other in the resinous state, nearly all the electricities being in the metallic linings. Hence, it is clear that, of the forces sought for, the vitreous was in one half of the compound plate, and the resinous in the other half; for, when removed bodily with their plates from each other's inductive influence, they appeared in separate places, and resumed of necessity their power of acting by induction on the electricity of surrounding bodies. Had the effect depended upon a peculiar relation of the contiguous particles of matter only, each half plate should have shown vitreous force on one surface, and resinous on the other.

It is the assumption, for a time, of this charged state of the glass, between the coatings in the Leyden jar, which gives origin to the phenomenon, which is called the *residual charge.* After a large battery has been charged for some time, and then discharged, it is found that it will spontaneously recover its charge to a very considerable extent; and this is due to the return of the electricity in the manner just described.

§ 335. Opposed to the phenomena of the *charge* which we have now examined, are those of the *discharge* of the electric forces, which yet remain for our closer investigation.

There are various modes by which this may be effected: the discharge by *conduction*, by *disruption*, and by *convection*, come before us on the present occasion.

§ 336. 1st. *The discharge by conduction* involves no chemical action, or displacement of particles.

Insulation and conduction might at first be supposed to be directly opposed properties of matter, but Dr. Faraday has shown that they are only extreme degrees of one common condition, and that they are connected by numerous intermediate links. At the two extremes stand the gases and the metals, and spermaceti is an example of a substance through which induction can take place, and also conduction; but both in a reduced degree.

A certain condition of particles which, if retained, constitutes *insulation*, if lowered by the communication of forces from one to the other, constitutes *conduction*. In the state of polarity or tension, the particles of all bodies (with the exception possibly of the gases) have a capability of communicating their forces in various times one to the other by which they are lowered, and discharge ultimately ensues. Shell-lac is the best insulator known amongst solids; that is to say, it retains its state of polarity most perfectly, but it becomes lowered in time, and is also capable of having that forced charge communicated to it which we have just described, and which is equivalent to conduction. The metals themselves, although such excellent conductors as to admit of the passage of electricity through them with a velocity which baffles the powers of conception, offer different degrees of resistance to its transfer: and such resistance is *pro tanto* insulating power.

§ 337. Mr. Snow Harris has contrived a beautiful apparatus for comparing this resistance of the metals. It consists of an air-thermometer, through the bulb of which, a wire of the metal to be examined, passes. By the passage of a definite portion of electricity from a Leyden jar through this wire, it becomes heated in proportion to its resistance, and this heat acting upon the air causes an expansion, which is measured by the liquid in the stem. The results of some of his experiments are comprised in the following table:—

TABLE XXXIII. *Electrical Conduction.*

	Heat evolved.	Resistance.
Silver	6	1
Copper	6	1
Gold	9	1½
Zinc	18	3
Platinum	30	5
Iron	30	5
Tin	36	6
Lead	72	12
Brass	18	3

The ready communication of forces between contiguous particles constitutes conduction; and the difficult communication insulation. Conductors and insulators are bodies whose particles naturally possess the property of communicating their respective forces easily, or with difficulty: the latter requiring the polar forces to be raised to a higher degree than the former, before this transference or communication can take place.

§ 338. The resistance of the metals, or their insulating power, may be brought into direct comparison with air, and even made to exceed it, by a very simple contrivance. Let one end of a very long wire be placed in connexion with the outside coating of a charged Leyden jar, and let it be doubled in such a way as to allow the other extremity to be brought very near, but not to touch the same coating with it. Let a connexion now be made by a discharging rod between the inside coating and this extremity of the wire, and if the distance be properly adjusted, the charge will pass in a spark through the interval of air between the two extremities, rather than traverse the whole length of the wire.

The middle part of the wire, therefore, acts as an insulating medium, and the tension which causes the spark at the extremities must exist throughout its length.

§ 339. The charge, as it passes through a metallic wire, momentary as is its duration, acts by induction through the air towards surrounding objects; and if the knob of a small Leyden jar be presented to such a conductor, a lateral spark will pass to it.

But the arrangement which exhibits this effect to the greatest advantage, is that of a long fine copper wire, insulated parallel to the horizon, and terminated at each end by a small ball. When sparks are thrown upon this from a globe of about a foot in diameter, the wire at each discharge becomes beautifully luminous from one end to the other, even if it be a hundred feet long: rays are given off on all sides perpendicular to the axis of the wire. When the long wire is arranged in two parallel, but continuous lines, by bending it, the outer side only of each arm becomes luminous. When formed into three parallel lines by a double bend, the middle portion of the wire does not become luminous, the outer sides only of the outer lines of wire exhibit the rays. When the wire is formed into a flat spiral, the outer spiral alone exhibits the lateral discharge; but the light in this case is very brilliant; the inner spirals appearing to increase the effect. The inner surfaces of the wires, in these latter cases, being all turned towards similarly-electrified surfaces, the lateral process of induction cannot of course take place.

§ 340. The substance of a wire may be so reduced, or the quantity of electricity so augmented, that the metal may be fused by the great heat evolved and scattered about with violence; and the resistance may even be sufficient to stop a portion of the charge. To produce this effect, it matters not whether the quantity employed be diffused over a large or a small surface, or what its original intensity may be, the same quantity will always fuse the same length of wire. Thus, if we measure a certain quantity of electricity into a Leyden jar, by the unit jar, so that the electrometer may indicate a high degree of tension, and measure the same quantity into a large battery, where the electrometer will exhibit a very low degree of repulsion, the effects upon a wire through which the two charges may be directed will be precisely equal. The intensity, in fact, in the wire, which is insufficient to carry the whole charge in either case, rises to the same degree.

§ 341. 2nd. The *disruptive discharge* takes place between two conducting surfaces, most commonly metals, by means of a dense bright spark in the substance of the intervening dielectric, when its particles have reached a certain degree of tension. It in every case displaces more or less the particles, amongst and across which it suddenly breaks. Every discharge in the form of sparks, brushes, and glow, are included under it; but currents of air or liquids, which sometimes accompany it, are essentially distinct in their nature, and will be afterwards considered. Disruption is the limit of the influence which the dielectric exerts in resisting the discharge. It is not necessary, probably, that all the particles should have attained this degree of tension, but when that particle which is most affected has been exalted to the subverting or turning point, all must give way, for all are linked together by the influence of the constraining force. All the particles in the line of induction resist change, and are associated together in their actions, so as to give a sum of resisting force; and the breaking down of one must cause the whole barrier to give way, which was at its utmost degree of resistance before the aiding power of that one was lost. The path of the spark depends upon the degree of tension acquired by the particles in the line of the discharge; circumstances which, in every common case, are very evident, rendering it higher in them, than in their neighbours, and by exalting them first to the requisite condition, causing them to determine the course of the discharge.

All the particles return to the original or normal state in the inverse order in which they left it, and exert their power meanwhile to produce the discharge effect in the few particles where the subversion of forces first takes place. These are probably not merely pushed apart, but assume a peculiar state for the time, or have thrown upon them all the surrounding forces in succession, and rising up to a proportionate condition, discharge themselves by some operation at present unknown, and thus end the whole. The ultimate effect is exactly as if a metallic wire had been put into the place of the discharging particles; and Dr. Faraday remarks, that not impossibly the principle of action in both cases may hereafter be proved to be the same.

The whole of the electricity passes between the two conducting surfaces in the form of a dense spark, and the discharge is complete.

§ 342. Though it cannot be doubted that the principal phenomena of the disruptive discharge depend upon the particles of the dielectric air, yet it appears that some of the metallic particles of the surfaces between which it passes are carried with it in its course. M. Fusinieri has remarked, that when a spark takes place between a surface of silver and another of copper, a portion of silver is carried to the copper, and of copper to the silver. Dr. Priestley observed, that if a metallic chain be laid upon a sheet of paper or a plate of glass, and a strong discharge sent through it, spots will be produced upon it of the size and colour of each link, parts of which will be found to be fused into the substance of the glass.

§ 343. We have already seen that disruptive discharge may take place in glass, in the case of a thin Leyden jar; and it may always be produced at pleasure, by bending a wire so that its point may press against the side of a tube filled with olive oil, or some other liquid dielectric. When such an apparatus is suspended from the prime-conductor of the electrical machine, a spark may be drawn through the glass to any conducting substance opposed to it, making a minute perforation without fracturing the tube. By turning the point round, or raising it higher or lower, many such holes may be made.

When the charge is high, a disruptive discharge will even take place, in the form of a spark, between two metallic wires in water.

§ 344. As the expansive force of the discharge is manifested even in good conductors by the fusion and dispersion of metallic wires of insufficient thickness, so may it be exhibited with equal or greater violence in bad conductors, by a variety of experiments.

Place a card or some leaves of a book against the outer coating of a Leyden jar; put one extremity of a discharging rod against the card, and bring the other extremity to the knob of the jar; the charge will pass through the paper and perforate it, producing a small bur or protrusion on the side next the rod, and a larger bur on the side which was in contact with the coating.

Drill two holes in the ends of a piece of wood, half an inch long, and a quarter of an inch thick; insert two wires in the holes, so that the ends within the wood may be rather less than a quarter of an inch distant from each other: pass a strong charge through the wires, and the wood will be split with violence. Loaf-sugar, stones, and many other substances may be broken in the same way.

Insert two wires through corks in the opposite ends of a glass tube; let the distance of the ends of the wires be about half an inch: fill the tube with water, and pass a charge through it; the tube will be broken, and the water dispersed.

§ 345. The instantaneity of the spark discharge is proved by the velocity with which its light passes away; its duration not being sufficient to illuminate two successive objects, or the same object in two positions, whatever may be the velocity of their motions. We have seen (§ 230) that when a disc painted with the prismatic colours is made to rotate very rapidly in common light before the eye, the distinction of colours is lost, and an impression of white light is produced. When a white disc, with a broad black cross upon it, is made to rotate in the same manner, the cross vanishes, and the disc appears of an uniform gray tint. When viewed by the flash of the electric spark, the colours appear distinct, and the cross sharply defined and perfectly stationary.

§ 346. By a beautiful application of this principle, Professor Wheatstone, (to whom the observation is due,) has contrived an apparatus by which he has demonstrated that the light of the electric discharge does not last the millionth part of a second of time. Let us imagine a small wheel of dull metal, marked with an hundred bright rays at equal distances from each other, made to revolve by clock-work ten times in a second of time; or to complete one revolution in the tenth of a second. These rays will be seen by the reflexion of an electric spark, and their appearance will be different according to its duration. If the time be infinitely short, the reflexion will present, during the tenth of a second, the appearance of one hundred fixed luminous rays of the same apparent dimensions as the engraved rays. If it last the thousandth part of a second, the whole circle will be full of light, for the impression of each ray upon the retina of the eye will remain till that of the succeeding ray is produced. For a duration of half a thousandth of a second, a third, a fourth, a fifth, &c., of the same interval of time, corresponding illuminated segments will be seen, and one-half, two-thirds, three-fourths, or four-fifths of the circle will appear completely deprived of light. By increasing the size of the revolving wheel, the scale of these measures may be increased at pleasure to any extent; as may also its subdivision, by increasing the velocity, or multiplying the number, of the rays. By altering the velocity of the rotation, the necessity of judging by the eye of the relation of the illuminated to the dark spaces may be obviated, and the whole may be reduced to a determination of the velocity at which the complete illuminated circle is produced.

§ 347. Although variations in the density of the air produce no changes in the inductive capacity of the dielectric, the distance at which spark discharge may take place through it, is greatly modified by its condensation or rarefaction. If two brass balls be placed within the receiver of an air-pump so contrived that their distance may be altered by passing the stem of the upper one through a collar of leathers, and if one of them be connected with the conductor of the electrical machine, it will be found that, as the air is exhausted, the distance through which the spark will strike may be greatly increased, and the tension of the charge will diminish, as shown by an electrometer upon the conductor. The intensity, in fact, of a charged surface, varies with the number of the particles of the dielectric over which its influence is diffused, and these depend upon the density of the medium, the form of the conductors, and the distances at which they are placed from each other. The rarefaction produced by heat acts in the same way as mechanical rarefaction; hence, flame, which is incandescent air, offers an easy passage to an electric charge; and in all electrical experiments its influence should be guarded against.

§ 348. Dr. Faraday also found that, independent of their density, different kinds of aëriform matter were capable of sustaining different degrees of tension. He constructed an apparatus, in which an electric discharge could be made along either of two separate channels; the one passing through a receiver filled with the gas which was to be the subject of the experiment, and the other having atmospheric air interposed. By varying the length of the passage through the latter, until it was found that the discharge occurred with equal facility through either channel, a measure was afforded of the relative resistances in those two lines of transit, and a determination consequently obtained of the *specific insulating power* of the gas employed. Muriatic-acid gas, examined by this method, had three times the insulating power of hydrogen, and nearly twice that of common air.

§ 349. The disruptive discharge sometimes changes its form from the spark to what is called the *brush*. It generally takes place between a good conductor and a bad conductor. When a pointed rod projects from a charged conductor into a room, induction takes place between it and the walls, or other surrounding objects, through the dielectric air, and the lines of inductive force accumulate at the end in greater quantity than elsewhere; that is to say, the particles at the end of the rod are more highly polarized there than at any other part of the rod. The particles of air situated in sections across the lines of force are least polarized in sections towards the walls, and most polarized in those nearer the end of the wire. Thus a particle at the end of the wire may be at a tension which will terminate in discharge, whilst in those only a few inches off, the tension shall be far beneath that point. A discharge, therefore, takes place between the rod and the particle in this exalted state, and the whole particle of the air becomes electrified similarly to the rod; this, again, exerts a distinct inductive act towards remoter particles, and the tension is so much exalted between the two nearest, that discharge takes place between them also, and the first particle renews its charge as before at the extremity of the rod.

§ 350. This form of disruptive discharge requires time for its propagation, and is a successive effect; for the particles in the line through which it passes are in very different states as to intensity, and the discharge at the root of the brush is already complete before the particles at the extremity of its ramifications have yet attained their maximum intensity.

If an insulated conductor connected with the positive conductor of an electrical machine have a metal rod of 0.3 inch in diameter, terminated by a round end projecting from it, it will generally give good brushes; or their formation may be assisted by holding the hand, or any other large conducting surface, opposed to it, thereby increasing the inductive force. Or they may be obtained of exceedingly fine character and great magnitude, by rarefying the air around the termination of the rod, more or less, by heat or the air-pump. The brush generally has a short, conical, bright part or root, projecting directly from the ball, which breaks out suddenly into pale ramifications having a quivering motion, and being accompanied at the same time with a low, dull, chattering sound, the evidence of intermitting action.

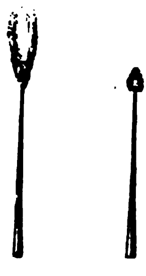
The brush may, in fact, be stated to be a spark to air, a diffusion of electric force to matter, not by conduction, but by disruptive discharge; a dilute spark, which passing to very badly conducting matter, frequently discharges but a small portion of the power stored up in the conductor. As the charged air reacts upon the conductor, whilst the conductor by loss of electricity sinks in its force, the discharge quickly ceases, until by the dispersion of the charged air, and the renewal of the excited conditions of the conductor, circumstances have risen up to their first effective condition, again to cause discharge, and again to fall and rise. This process is nearly instantaneous, but, unlike the spark, has a sensible duration, as has been proved by the beautiful experiments of Professor Wheatstone.

§ 351. Dr. Faraday has shown, that the brush has specific characters in different media; these are manifested by differences of colour, light, form, and sound. This effect is in strong contrast with the non-variation caused by the use of different substances, as the conductors from which the brushes originate, which had no sensible influence upon their characters. Nitrogen, of all the varieties of aëriform matter, possesses the highest power of originating and effecting discharge in the form of brushes and ramifications, and as this gas enters in the proportion of four-fifths into the constitution of our atmosphere, it has probably an important relation to electricity, seriously affecting the character and condition of the discharge when made in the grand laboratory of Nature.

§ 352. There is a very striking difference also in the appearance of the brush discharge, according as it takes place at a vitreous or resinous surface: the effect varies exceedingly under different circumstances. If a metallic wire with a rounded termination, in free air, is used to produce the discharge, then the brushes obtained when the wire is charged resinously, are very poor and small, by comparison with those produced when the charge is vitreous. The former sometimes appear as a bright star, while the latter are pale and expanded. Or if a large ball be charged vitreously, and a fine uninsulated point be gradually brought towards it, a star appears upon the point when at a considerable distance, which, though it becomes brighter, does not change its form until it is close up to the ball: whereas if the ball be charged resinously, the point, at a considerable distance, has a star on it as before; but when brought nearer, a brush forms on it, extending to the ball; and when still nearer, bright sparks will pass. The resinous surface tends to retain its discharging character unchanged; whilst the vitreous, under similar circumstances, permits of great variation (87).

When two equal small conducting surfaces similarly placed in air are electrified, one positively and the other negatively, that which is negative can discharge to the air at a tension a little lower than that required for the positive ball; and when discharge does take place, much more passes at such time from the positive than from the negative surface.

§ 353. Very important variations of the relative forms and conditions of the resinous and vitreous brush, take place also on varying the dielectric in which they are produced, which point to a specific relation of this form of discharge to the particular air in which it



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(87) Some notion may be formed of the difference between the brush and the star appearance, from the annexed representation of the disruptive discharge from points.

takes place; proving that direct relation of the electric forces to the molecules of the matter concerned, which Dr. Faraday has established in so many other instances. The effects are due altogether to the different modes in which the particles of the interposed dielectric become polarized.

§ 354. Sometimes a rod which has been rendered vitreous, and given off fine brushes from the extremity, will have its end covered with a quiet phosphorescent continuous *glow*, extending a very small distance from the metal into the air. Diminution of the charging surface will commonly produce this effect. With a rod of 0.2 inch in diameter it is readily manifested. With still smaller rods, and with blunt conical points, it occurs still more readily, and with a fine point in free air no brush occurs, but only this glow. The vitreous glow and the vitreous star are in fact the same.

Rarefaction of the air greatly favours the glow phenomena. Brass balls of two inches diameter will become covered with glow over an area of two inches diameter, when the pressure of the air is reduced to about 4.4 inches of mercury; and by a little adjustment the ball may be covered all over with this light.

The glow is always accompanied by a wind, proceeding either directly out from the glowing part, or directly towards it: the former being the most general case; and if matters be so arranged that the regular and ready access of air to a part exhibiting the glow be interfered with or prevented, the glow disappears.

Brush discharge does not essentially require any current of the medium in which it appears: it almost always occurs, but is a consequence of the phenomenon. On holding a blunt point vitreously charged towards uninsulated water, a star or quiet glow will appear upon it, and the surface of the water will be depressed by the current of air which passes from it; but on approaching the point nearer, sonorous brushes will succeed, the current of air will instantly cease, and the surface of the water become level.

§ 355. All the effects tend to show that *glow* is due to a continuous charge or discharge of air; in the former case being accompanied by a current from, and in the latter by one to the place of glow. As the surrounding air comes up to the charged conductor, on attaining that spot at which the tension of the particles is raised to a sufficient degree, it becomes charged, and then moves off by the joint action of the forces to which it is subject; and at the same time that it makes way for other particles to come and be charged in their turn, actually helps to form that current by which they are brought into the necessary position. Thus, through the regularity of the forces, constant and quiet results are produced, namely, the charging of successive portions of air, the production of a current and of a continuous glow.

A brush may often be converted into a glow, simply by aiding the formation of a current at its extremity; and on the other hand the glow may be converted into a brush by sheltering the point from the approach of air.

A continuous discharge of electricity to the air gives the glow; an interrupted one produces the brush, and in a more exalted condition the spark.

§ 356. We are thus brought to the consideration of the *discharge by convection*, or carrying discharge. It often, as we have just seen in cases of brush and glow, joins its effect to disruptive discharge to effect the neutralization of the electric forces.

The particles which, being charged, travel, may be either of insulating or conducting matter, large or small. We shall best understand the different steps of the process by considering a particle of conducting matter.

Dr. Faraday illustrated it by insulating and electrifying a large copper vessel, (a boiler of three feet diameter,) to the degree that dissipation by brushes or disruptive discharge did not sensibly take place at its edges. A brass ball, two inches in diameter, suspended by a silk thread, was brought towards it; and it was found that if the ball were held for a second or two, near any part of it, at a sufficient distance (almost two inches,) not to receive any direct charge from it, it became itself charged, although insulated the whole time; and its electricity was *contrary* to that of the boiler. The effect was strongest opposite the edges, or other projecting parts, where it is well known that the original charge is the strongest.

This effect is obviously one of induction, and not of communication. The ball, when related to the vitreously-charged surface by the intervening dielectric, has its opposite sides brought into contrary states; the side next to the boiler being resinous, and the outer vitreous. More inductive action is directed towards it than would have passed across the same place if the ball had not been there, for several reasons: amongst others, because it being a conductor the resistance of the particles of the dielectric, which otherwise would have been there, is removed; and also because the reacting vitreous surface of the ball being projected further out from the boiler than when there is no introduction of conducting matter, is more free to act towards surrounding conductors, through the rest of the dielectric, and so favours the exaltation of that inductive polarity which is directed in its course. It is the same as if the surface of the boiler itself were protuberant in that direction. Thus it acquires a state similar to, but higher than, that of the originally charged surface which causes it; and sufficiently exalted to discharge at its vitreous surface to the air, or to affect small particles as it is itself affected; and they flying to it, take a charge and pass of; and so the ball as a whole is brought into the contrary charged state. The consequence is that, if free to move, its tendency to approach the boiler is increased, whilst it at the same time becomes more and more exalted in its condition, both of polarity and charge; until at a certain distance discharge takes place; it acquires the same state as the boiler; is repelled, and passing to a conductor favourably circumstanced to discharge it, there resumes its first neutral condition.

In the case of elongated, or irregularly shaped conductors, such as floating filaments or particles of dust, this effect is still more ready, and the consequent attraction very immediate.

§ 357. On using a liquid dielectric, as oil of turpentine, the action and course of small carrying particles is very striking.

The analogy between the action of solid conducting, carrying particles, and that of the charged particles of an insulating fluid substance is very evident and simple; and in the latter case, currents are necessarily occasioned in the dielectric. Particles are brought by inductive action into a polar state; and this state, after rising to a certain tension, is followed by the communication of a part of the force originally on the conductor; the particles consequently become charged, and then, under the joint influence of the repellent and attractive forces are urged towards a discharging place, or to that spot where these inductric forces are most easily compensated by the contrary inducteous forces.

The course of these convective currents may be beautifully illustrated by using oil of turpentine as the dielectric; provided it be placed in a wide vessel, sufficiently capacious to include all the lines of inductive force. The attraction is so great that if a small ball at the end of a metallic stem be held in the hand, and immersed below the surface of the liquid, in the inducteous state, a considerable column may be raised up, in which the phenomena of the ascending and descending particles will be very apparent.

If a piece of sealing-wax be fastened to a wire, and this be inserted into the conductor of the electrical machine, upon softening the wax by heat, and turning the machine, very fine threads will be separated, and if received on a sheet of paper will cover it with minute fibres, like fine red wool. These, again, are evidence of the force with which convection is carried on.

§ 358. The force of the convective discharge will be always greatest from a point, for reasons which must be very obvious from the principles of action which have been explained. The lines of inductive force are concentrated upon the extremity of the point, and it is there consequently that the intensity necessary to charge the air is first acquired; it is from thence that the charged particle recedes, and the mechanical force which it impresses on the air to form a current is in every way favoured by the shape and position of the rod of which the point forms the termination. At the same time the point, having become the seat of an active mechanical force, does, by the act of discharge which causes it, prevent any other part of the rod from acquiring the same necessary condition, and so preserves its own predominance.

§ 359. Light models fitted up with vanes, like the floats of a water-wheel, may be put in motion by the current of air produced by the action of an electrified point; and if a lighted taper be presented to such a current, its flame will sometimes be blown out, (88).

If a point be enclosed in a glass tube so that it may be placed at any distance from one of the open ends of the tube, its influence as a point will be destroyed, and it will transmit electricity by sparks

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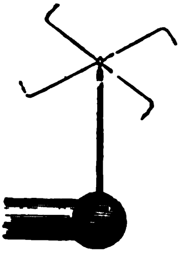
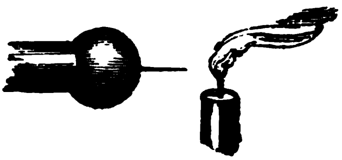
(88) This figure represents a light cross of wire, turning upon a point, placed upon the prime conductor. The air is forcibly driven from the points, and by its reaction impels the vane in the opposite direction.



The flame of a taper is here represented under the influence of the air, passing off from a point, upon a charged electrified conductor.



as a ball. The access of fresh uncharged air is thus stopped, and the process of convection cannot proceed.

§ 360. The light which accompanies the disruptive discharge of the electrical forces is accompanied by heat, and is capable of igniting inflammable substances, such as ether, rosin, &c.; but its duration is so momentary, that sometimes it fails to produce this effect. If a little loose gunpowder be placed in a break between two wires, and a discharge be made through it, the grains will generally be scattered about without explosion; but if the electrical force be first made to traverse a portion of water, or other imperfect conductor, it will in its discharge inflame the powder. This difference seems to be accounted for by supposing that the course of the electricity is retarded, so that it has time to produce the effect which its more rapid transit through a good conductor would not allow of its producing. The light and heat which thus accompany the discharge of the electric forces, in their exalted state, amongst the polarized particles of a dielectric, are probably perfectly analogous to the ignition and heat which are produced by the tranfer of the same forces, in a much lower degree of tension, amongst the particles of a good conductor, whose substance is insufficient to effect their complete neutralization.

§ 361. The relations of the surfaces and distance of two conductors, under the influence of the electric forces exerted through the intervention of dielectric air, have been accurately measured, calculated and determined by Coulomb and Snow Harris.

Let us imagine a small metallic sphere, placed in the centre of another large metallic sphere filled with air (fig. 72); a charge of electricity may be communicated to the former, which will be sustained by induction to the surface of the latter, and every molecule of the air will be related to every other molecule in all directions, by the tension and reaction of those which are contiguous. The quantities of the opposite forces upon the inductric and the inducteous bodies must be exactly equal; but their intensities will be very different. The lines of inductive force which will be spread over the whole surface of the latter will be concentrated upon the former. An electrified ball placed in the centre of a large room, and equally removed from all surrounding objects and irregularly-formed conductors, does not differ appreciably from such a hypothetical arrangement, and Dr. Faraday has experimentally traced the induction under such circumstances to a distance of twenty-six feet. Under these simple conditions, supposing the central ball to be indefinitely small, the lines of inductive force will radiate from the centre, and the resulting attraction will follow the law of radiant forces, and decrease in direct proportion to the squares of the distances.

The result may otherwise be stated thus:—the sum of forces in spheres of different diameters, surrounding an active centre, must be always equal; and the amount in any two similar sections equal. The law is the same as that of light, and is a necessary consequence of the theory of induction in this the simplest case of the action of contiguous particles.

The experimental investigation, and mathematical calculation of the laws of electrical attraction and repulsion, have been hitherto limited to cases which may be resolved into this radiant action, and have not as yet been applied to cases of induction in curved lines.

§ 362. The torsion electrometer, by means of which Coulomb carried on his investigations, has been already described; Mr. Harris adapted the simple balance in the most ingenious and effectual manner to the same purpose (89). In the first instrument the force of elasticity is opposed to, and made the measure of, electrical attraction; in the second, the force of gravitation is applied to the same purpose, and the electrical attraction actually weighed.

If a certain quantity of electricity be measured into a large Leyden jar, by means of the unit jar, and two planes connected with the two coatings be found to attract each other with a force of 4.5 grains, with double the quantity 18 grains would be required

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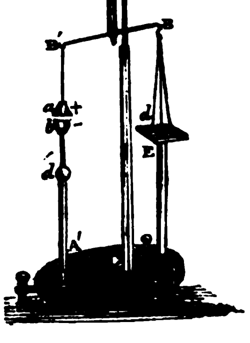
(89) This figure represents Harris's electrical balance. A glass pillar is fixed in the stand A, to which the beam of a delicate balance, B B, is suspended at the point, D. A scale pan, *d*, is suspended from one arm, and just rests upon the support, E, likewise, insulated and fixed upon the stand, A. From the other arm is suspended a light gilt cone, *a*, the base of which is opposed to the base of another inverted cone, *b*, which may be fixed at any distance from it by sliding upon the insulated pillar, *d*. The metallic balance may be connected with the interior of a Leyden jar, or battery, and the cone, *b*, with the exterior, and the attractive power of any charge at any variable distance between the cones, may be estimated by weights placed in the scale pan.



to counterbalance the force, and with treble the quantity 40.5 grains.

When a second and equal jar is connected with the first, similar quantities only exhibit $\frac{1}{4}$th of the preceding forces, respectively; and when the same quantities are diffused over three such jars, the respective amounts are only $\frac{1}{9}$th.

§ 363. Hence, when the quantity is constant, the attractive force is as the squares of the surfaces inversely; and when the surface is constant, as the squares of the quantities directly.

Again, it is found that the respective quantities requisite to produce a discharge between two balls, vary directly as the distances; so that, while the distances of discharge increase in the simple ratio of the quantity, the attractive forces increase as its square.

§ 364. Mr. Harris also found, that the attractive force is not influenced by the form of the unopposed portions of the acting conductors, and that it was the same, whether simple circular planes were opposed to one another, or cones by their similar plane bases. Two hemispheres also attracted one another, with the same force as spheres of the same diameter.

The attractive force between two unequal circular areas is no greater than that between two similar areas, each equal to the lesser; and the attractive force of a mere ring and a circular area, is no greater than that between two rings of the same diameter.

§ 365. The general result may thus be stated:—the force of attraction is as the number of points in immediate opposition directly, and as the square of their respective distances inversely; hence, the attractive force between two parallel plane circles being found, the force between any other two similar planes will be given.

The respective quantities requisite to a discharge through a given interval of air, vary in the simple ratio of the density of the air: when the density is one-half, the discharge occurs with one-half the quantity accumulated, or, which is the same thing, with one-fourth the intensity. Again, when the intensity is constant, the discharge occurs in air of one-half the density at double the distance.

The influence of heat is not in any way opposed to the restraining power of air, provided its density is not allowed to vary; but rarefaction by heat produces exactly the same effect as mechanical rarefaction.

§ 366. These results are in perfect accordance with the molecular theory of induction: for, in the case of an atmosphere rarefied to one-half, only one-half of the dielectric particles remain, and these are brought up to the discharging intensity with one-half the quantity of electricity. And with regard to distance from an inductive centre, the number of particles which become polarized within any concentric sphere, or any section of such sphere, must increase as the square of the diameter, and the force will be lowered in the same degree.

§ 367. We have hitherto directed our attention solely to one method of exciting the electrical forces; namely, the friction of dissimilar substances, by which their particles are rapidly brought into close contact and as rapidly separated. By this operation, we have found particularly that the rubbed surface of a dielectric becomes inductric; its charge being sustained both through its own substance, and through the air to surrounding conductors. But there are many other methods by which this extraordinary agent may be developed; and indeed, the forcible disturbance of the established equilibrium of the particles of bodies in any way seems sufficient to call it forth in various degrees. Thus, the forcible disruption of cohesion; mere pressure upon certain crystallized substances; the heating of others; changes of physical state; crystallization and evaporation are all capable of producing electrical excitement.

§ 368. If we break a roll of sulphur we shall find a charge of electricity upon its two fresh surfaces, and if we pound it in a dry mortar and pour the fragments upon the glass of an electrometer, the leaves will diverge very forcibly; and if we renew the contact with fresh surfaces upon a fresh plate, we shall find that it is not easy to deprive it of the whole quantity which it has thus acquired.

If we take a rhombohedron of Iceland spar, and, holding it by two opposite edges, press upon two of its opposite faces, it will manifest a decided power of attraction upon light substances.

§ 369. Crystals of tourmaline, again, whose optical properties have been described (§ 245), exhibit a very remarkable state of electrical excitement when gently heated. The tourmaline is a hard crystallized mineral, which occurs in granite and other primitive rocks, in the form of three, six, or nine sided prisms, terminated by three or six sided pyramids. It was discovered by the Dutch in Ceylon, who called it *Aschen trikker*, from its property of attracting ashes when thrown into the fire. It appears however to have been known to Theophrastus. When the stone is of considerable size and warmed, flashes of light may be seen to dart across its surface when laid upon a hot iron. If a crystal of this mineral be mounted upon a pivot, or otherwise suspended with freedom of motion, its excitement will be found to be polar, and one end will be attracted by excited glass and the other repelled. The polar arrangement of its particles exists throughout its substance, for, when broken in two, each half will prove to be likewise polar. It is during the rise of its temperature that these phenomena take place: during the process of cooling they also occur, but with the opposite direction of the forces.

The poles of the mineral have reference to the axis of symmetry (§ 124), and those crystals are alone electrical, the opposite extremities of whose axes differ with regard to the number, disposition, and figure of their facets.

§ 370. Boracite is another mineral which possesses the property of becoming electric by heat in a high degree. It crystallizes in the form of a cube; but the edges and angles are generally replaced by secondary planes, and four of the angles are always observed to present a greater number of facets than the other four: the most complex angles are rendered vitreous, and the simplest resinous, by heat, and these are always found at the opposite extremities of the axis of symmetry.

§ 371. If melted sulphur be poured into a glass vessel, it becomes electrical in the process of crystallization; and if it be removed from the glass and examined after solidification, it will be found in the resinous state, and the glass in the corresponding vitreous state. Water, also, in the act of freezing, becomes electrical.

The evaporation of water likewise excites electricity, and if a heated platinum vessel be placed upon the cap of a gold-leaf electrometer, and water dropped into it as the steam flies off the leaves will expand with resinous electricity. The effect is rendered very decided with the assistance of the condenser. The late experiments of M. Pouillet have rendered it probable that the evaporation of perfectly pure water is not accompanied by any development of the electrical forces, but that a very minute portion of saline matter in solution is sufficient to determine the effect. This does not detract from the probability of evaporation being the principal source of atmospherical electricity; for all the water upon the face of the globe is impregnated more or less with different salts. The vitreous electricity which corresponds to the resinous charge, which in the experiment is left upon the electrometer, is carried into the air, and probably communicates a charge to the minute drops into which it is again condensed, and which float in the atmosphere.

§ 372. At a very early period of electrical science the identity of the electric spark and lightning was suspected; for Dr. Wall, in 1640, in contemplating the light and crackling noise produced by the friction of a large piece of amber, was led to remark that this crackling and light may be supposed in some degree to represent thunder and lightning. But it was Franklin who, in 1747, established the close analogy of the two agents, by strict inductive reasoning, and experimentally verified his conclusions by imitating, on a small scale, the awful phenomena of nature. He had also devised the *crucial experiment*, of drawing electricity from the clouds, by means of an insulated pointed rod of metal, for the erection of which he only waited the completion of a church steeple in Philadelphia. But M. Dalibard, in France, preceded him by about a month in obtaining the actual result, by repeatedly charging a Leyden jar by means of a similar apparatus during the passage of a thunder cloud. Without any knowledge of this experiment it occurred to Franklin, whilst occupied with the subject, that by means of a common school-boy's kite he might obtain ready access to the region of the clouds. He watched the opportunity of an approaching storm and went into the fields, and, with the assistance of his son, raised the kite into the air. He confined it by two or three feet of silken ribbon, but a considerable time elapsed without any result. One very promising cloud passed over his head without producing any effect upon his simple apparatus, when, being about to give up the attempt in despair, he observed, after a sharp shower, some loose threads of the string to repel one another; on this he fastened a key to the string, and was gratified by drawing an electric spark from it. He afterwards raised an insulated metallic rod from the end of his house, so arranged as to communicate with two bells by means of a pendulum which, striking against them as they were alternately attracted and repelled, warned him of the passage of an electric cloud (90).

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(90) The chime of bells, represented in the next figure, is suspended to the electrified body by the metallic hook, *a*. The two exterior bells, *b b*,

The experiment with the kite has often since been repeated, with the addition of a thin copper wire twisted with the string; but it is not unaccompanied with danger, for experimenters have frequently received violent shocks, and the electricity has been known to discharge itself to the ground in sparks ten feet long, and two or three inches in diameter. A fatal catastrophe from incautious experiments upon atmospheric electricity occurred to Professor Richman, of St. Petersburg, in 1753. He had erected an apparatus in the air, and was examining it with a friend, when a flash of lightning passed from the insulating rod through his body, and instant death was the consequence. His companion was at the same time struck senseless to the ground.

§ 373. The snapping noise which the electric spark makes in passing through a portion of the atmosphere is due to the sudden compression of the air; and there can be no doubt that the awful thunder-clap itself is produced by the same action. The report is in this extreme instance modified by a variety of circumstances, such as distance, echo, &c.; and the sudden dying away and return of the sound may be accounted for on well-known principles.

We have already stated (§ 12) that sound travels in air with a velocity of only 1,130 feet in a second, but light at the rate of 195,000 miles in the same period of time (§ 216). The time in which the flash of lightning reaches us, from the different points of its course, may therefore be taken as instantaneous; but the time which the explosion occupies will be very appreciable, and will vary with the distance of the several parts of the long line which the discharge traverses. By a calculation founded upon the interval between the flash and the sound, and the duration of the thunder-clap, it has been found that a flash of lightning frequently traverses a space of nine or ten miles; and, when we take into account the zig-zag path which it ordinarily

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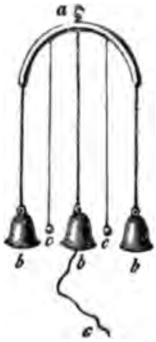

are in metallic communication with it, and the centre one is insulated by a silk-thread, but is in metallic communication with the ground, by the chain, *c*. The metallic clappers, *c c*, are suspended by silk threads, and when the exterior balls are charged they are alternately attracted and repelled, and discharge the electricity by convection to the centre conducting-bell.

follows, its alternate approach and recession will account for the phenomenon in question. Such would be the effect produced upon an observer, placed at the end of a long file of soldiers, who were to discharge their muskets at the same moment. He would not hear a single report, but a succession of reports, which would produce an irregular rolling sound (91).

§ 374. If a house stand in the way of an electric discharge, that is to say, if it form by induction from the charged clouds a part of that line of particles which have attained the highest degree of tension, the course which the lightning will take will be determined by the accidental position of different conducting bodies within it, which

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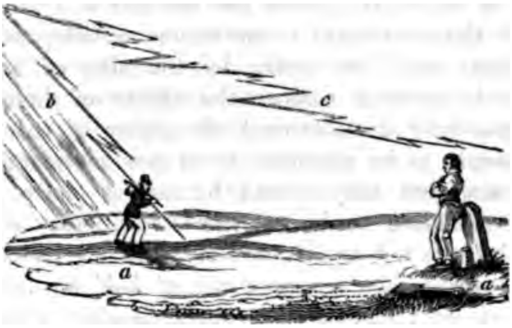
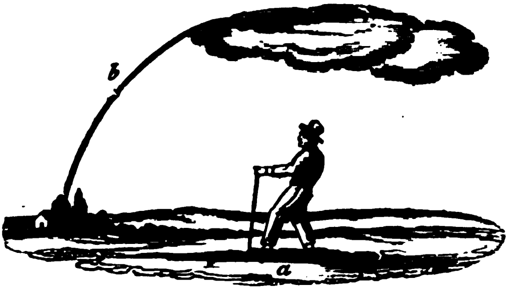
(91) The usual zig-zag path of a flash of lightning is here represented. The sound will reach the observers, placed at *a* and *a*, from the different points, in very unequal times, and will sometimes recede and then approach alternately, as it reaches them from the further or nearer portions of the atmosphere in which the concussion is produced.





Sometimes the discharge follows a path approaching to a segment o
a circle, and then, if the observer be placed in a situation nearly equidistant from every part of the flash, it will affect him with a single crash.

will change the line of greatest tension according to their relative situations. Thus it is probable that it may descend a chimney in which the air is rarefied; or it may strike the same object from being the most elevated conducting body in its course. It may then leap to different metallic articles in the chambers,—or even to persons, whose good conducting properties may present an easy transit in the position in which they may be placed; it will finally pass to the earth, after having thus followed the path which had been previously determined by the arrangement of the particles under the highest state of inductive influence. As long as the discharge is confined to the good conducting substance of metals lightning produces no injurious effects; but whenever it passes from these into imperfect conductors its course is marked by destruction.

§ 375. To Dr. Franklin belongs the honour of having suggested the application of the known principles of electrical science to the defence of buildings against the dangers of a thunder-storm. He proposed the erection of a continuous metallic rod in perfect communication with the earth, by the side of any building intended to be secured against the effects of lightning; and experience has fully demonstrated the utility of this precaution. The great points to be attended to in the construction of such conductors are, that they should be carried above the highest point of the building to be protected,—that they should be of sufficient substance not to be melted, and the experience of a century has proved that a copper rod of half an inch diameter has never yet been fused;—that there should be good metallic contact in all their parts;—and that they should terminate at a sufficient depth in the ground, and be led, if possible, into some piece of moist earth, or large body of water. It has been proved that conductors erected with these precautions will protect a circular space of a radius double their height above the highest point of the building to which they are attached.

§ 376. An objection, founded in ignorance, has sometimes been made to lightning-rods, that they may by their attractive power invite a discharge where otherwise it would not have taken place. But when it is considered that one of the conditions of a thunder-storm is an intense electrical induction of a portion of the earth's surface through a dry stratum of air to the surface of a cloud of some thousands of acres in extent, in the manner of a Leyden jar, it will be perceived that any such elevation as compared with the distance and extent of the charged clouds, is utterly inconsiderable, and perfectly inadequate to influence the charge in the slightest degree. The conductor is perfectly passive, and its efficacy consists in opening an easy path by which the force may be transmitted. Its action is at best but of a negative kind, and it can no more be said to attract the lightning than a watercourse can be said to attract the water which necessarily flows through it at the time of heavy rain.

It is true that a pointed conductor will silently draw off a considerable portion of the electric charge from a distant cloud, and this action will sometimes be indicated by a glow, or even brush, upon its extremity, but this would tend to diminish the state of tension of the charged masses; and if inadequate to produce an appreciable diminution of the enormous quantities collected, can have no influence in exalting the tension to the point of disruption.

§ 377. The beautiful meteor called the *aurora borealis*, there can be little doubt, is another form of electrical discharge taking place in the upper regions of the atmosphere, where the decreased density of the air admits of those brushes and coruscations which can be so well imitated in the receiver of the air-pump. Luminous brushes, aigrettes, and glows, have not unfrequently been observed also, previous to thunder-storms, upon the mast-heads of vessels, the points of soldiers' spears, and even upon the outstretched fingers of the hand. Upon the high table-land of Mexico, where the atmosphere at times is extremely dry, the horses' manes become luminous and emit a crackling noise. These lights used formerly to be regarded with feelings of dread and superstition, and went in Italy by the name of the Fire of St. Elmo.

§ 378. The atmosphere, though not usually charged to the excess which is necessary to produce the phenomena to which we have just adverted, will commonly afford indications of electrical excitement. In calm dry weather, when no clouds are visible, the gold leaves of an electrometer armed with a pointed rod or flame, will always indicate vitreous electricity; and it has been ascertained that its intensity is subject to regular variations, reaching a maximum about seven or eight o'clock in the morning, and falling to a minimum between one and two. In high winds and damp weather, without rain, electrical indications can rarely be obtained; and in cloudy weather, and in times of showers of hail, rain or snow, they vary very much both as to kind and intensity.

§ 379. At a very early period it had been observed that, when vessels at sea had been struck by lightning, their compasses were often deranged; and in some instances the polarity of their needles, or their property of pointing north and south, destroyed, in others reversed. Dr. Franklin also succeeded in imitating this effect by frequent discharges of the electrical battery. Up to a very recent date, however, there has always been great uncertainty in the results of the experiment; but the conditions of its success have lately been determined, and by wrapping a wire spirally round a glass tube, so that the convolutions shall not touch each other, and placing the needle within it while a strong discharge is directed through the wire, these effects will be produced. If a common steel needle, without any attractive power, be placed in similar circumstances, it will be found to have acquired the power of attracting iron filings, and all the properties of MAGNETISM.

We will now, therefore, proceed to inquire into the nature of this new force, and the laws which govern its action.

MAGNETISM.

§ 380. The force or forces of MAGNETISM we have already distinguished, (§ 15), as they reside in the loadstone; or as communicated by friction from that species of iron ore to bars of steel. The first observed phenomena of magnetism did not, like those of electricity, remain for some thousand years a barren discovery; for the polarity of a magnetic bar, or its property of always pointing towards the North Pole of the earth, was long since rendered subservient to navigation. It is said, that the Chinese and Arabians were acquainted with this directive power before the Europeans, and that they employed it even one thousand years before the Christian era.

Mr. Davies has informed us, that it is explicitly mentioned in a Chinese dictionary finished in A.D. 121; and in another dictionary completed in the reign of Kang-hi, he says, it is stated that under the Tsin dynasty, (previous to A.D. 419,) ships were steered to the south by the magnet.

With regard to Europeans, the only certain fact concerning the early application of the property is, that Vasco de Gama, a Portuguese navigator, employed the compass, in 1497, in his first voyage in the Indian Seas.

§ 381. Let us now examine the phenomena with more precision.

If a long bar magnet be covered with iron filings, and then withdrawn from the heap, it will be found that a portion of the filings adhere to its surface, but in a very unequal manner: large clusters will be suspended from the two extremities, but not a particle will be attached to the centre between them (92). It may also be observed that long filaments, composed of many smaller ones joined end to end, will stand erect from the ends; but that as they recede from these points, they will be shorter and shorter, and incline from each other, appearing to be self-repelled. The best mode of examining the attractive points of such a bar is to place it under a sheet of paper, upon which iron filings may be sifted. By gently tapping the paper, they are slightly projected into the air, and, as they fall under the influence of the magnetic attractions, they distribute themselves into regular and beautiful curve lines which converge towards the extremities where they are collected in largest quantities. These points of attraction are the poles of the magnet: that is, points endued with similar, but opposed, forces of attraction and repulsion, analogous to those which we found in an insulated electrical conductor under induction. A needle of soft iron, freely suspended from a silk thread, will be attracted precisely in the same way as the iron filings; but a magnetic needle of steel will be attracted by one extremity, and repelled by the other. These phenomena take place through interposed metals, glass, rosins, water, paper, &c., and are clearly distinguished from their analogous electrical attractions and repulsions.

§ 382. Sometimes a bar which has not been magnetized to saturation will present points which have been called consecutive poles, indicating alternation of the two magnetic forces. These may be discovered by the grouping together of iron filings, or by the alternate attractions and repulsions of the bar at the different points when freely suspended.

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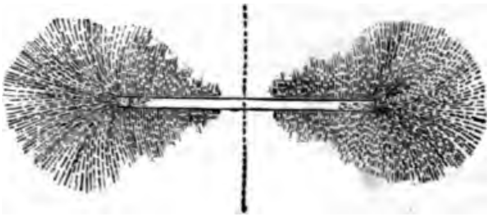
(92) If a magnetized bar be placed on a sheet of paper, and iron filings be sifted upon it, they will adhere to it in the manner here represented.



§ 383. Soft iron becomes magnetic by induction from a magnet, just as an insulated cylinder of metal becomes electrical by the action of an electrified body through the air. If a key, or other piece of iron, be held near one of the poles of a powerful loadstone or magnet, it will be found that a series of iron balls and needles may be suspended from it, each in succession becoming polar under the influence of the inducing force (93). When the magnet is withdrawn, they all immediately return to their neutral state.

The opposition of the poles may be well shown by suspending two small iron cylinders, side by side, in contact, and approaching them with the pole of a magnet; each will become temporarily magnetic; and each will have its nearest end converted into an opposite pole to that of the magnet: the similar poles of the two cylinders will consequently be in contact, but will immediately repel each other, and the cylinders will fly apart (94).

If a quantity of fine iron wire be cut into lengths of about one-eighth of an inch, large quantities of it may be suspended from a magnet; which will exactly represent the black silk threads which we have before examined under the inductive influence of electricity in spirits of turpentine. (§ 314.)

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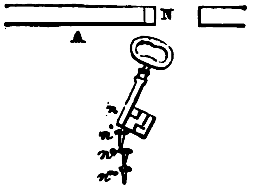
(93) A represents a bar-magnet, near to the marked extremity of which, N, a key is held: this will become magnetic by induction, and will induce magnetism upon the three small nails brought near it, which will be consequently attracted. The positions of the marked poles of these temporary magnets are indicated by the letters n'' n''' n'''', when the key is gradually removed from the influence of the magnet, the iron nails successively fall off.



(94) When the unmarked pole of a magnet, s, is held at a little distance from two pieces of soft iron, suspended from a point by two pieces of thread, (fig. 1), they both become magnetic by induction, and the two similar poles, *n n*, and the opposite poles, *s s*, repel one another. If the pole of the magnet, s, (fig. 2), be approached nearer to them, its superior attraction will overcome the mutual repulsion of the poles, *n n*, and they will be drawn towards it, but the poles, *s s*, will separate to a greater distance than before.

Fig. 1.

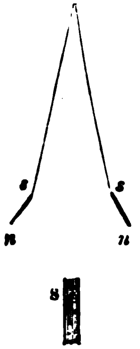
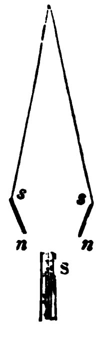


Fig. 2.



§ 384. The magnet, like the charged electrical conductor, loses none of its original force while communicating this induced power; but, on the contrary, it has its own state exalted by the reaction of the opposite power it thus develops.

§ 385. There is, however, an essential difference in the character of electrical and magnetical induction: we have seen (§ 312) that if a cylinder under electrical induction be broken in two, each half will retain an opposite charge independently of the other; but if, under similar circumstances of magnetic influence, an iron wire be cut in two, the end which is removed will show no signs of free magnetism. Under no circumstances, indeed, can one magnetic force be obtained in any form of iron without the coexistence of an equal amount of the opposite force in the same mass: and if we fracture a magnet, or loadstone, into any number of pieces, each fragment will be a perfect magnet with contrary poles.

§ 386. We may suppose a mass composed of minute grains of metal, each surrounded by a non-conducting substance not adding sensibly to its bulk: on bringing a body thus constituted near an electrified body, every one of the grains would immediately become electrical by induction; and it has been mathematically proved, that the attractions and repulsions which such a body would exert externally, would be the same as those of a homogeneous conductor of the same form and size, subjected to the same inductive influence. In the latter case, however, the two forces would be transferred to the opposite extremities of the body; while in the former they would remain in the masses to which they originally belonged. Such, in fact, appears to be the disposition of the electric forces in the tourmaline (§ 369), and it offers an excellent illustration of the disposition of the forces in the magnet.

§ 387. Hence we may conclude that magnetic induction takes place in consequence of the complete and separate polarization of each particle of iron, and that the forces cannot travel from one to the other to accumulate at the ends like the electric forces in an insulated conductor.

Iron filings, by their mere juxtaposition, under the influence of a magnet form a series of minute magnets, of which the poles are similarly situated in each; and, being alternately of different kinds, the adjacent ends attract one another. An accumulation of such filings between the opposite poles of two magnets, or of a magnet bent into the form of a horse-shoe, accurately represents a bar of soft iron placed in the same position, and the particles of both we conceive to be precisely in the same condition.

Separate magnetic charges cannot be supported by distant bodies, by a polarization of the particles of the intervening air, equivalent to that which sustains a charge of either of the electrical forces. The magnetic forces traverse all substances except iron and one other metal, nickel, without affording any indications of that action upon their particles, which has so lately been established by Dr. Faraday in the case of the electrical forces.

§ 388. Perfectly pure soft iron returns immediately to its neutral state upon removing the inducing cause or pole of the magnet; but if the natural arrangement of the particles of the metal be disturbed by mechanical force, such as twisting or violent hammering, it will retain its polarity for longer or shorter periods. The new arrangements which take place from chemical combination also confer this retentive or coercive power in a high degree: hence, the permanence of the magnetic forces in the loadstone, which is an oxide of iron, and in hard steel, a compound of carbon and the same metal.

§ 389. The process of induction takes place very slowly in tempered steel by mere contact; the coercive power which retains the particles in their polarized state, when once acquired, opposing itself to its reception: but it is greatly facilitated by friction. When one pole of a powerful magnet is rubbed two or three times along a bar from end to end, always in the same direction, the latter speedily acquires the magnetic virtue. Various modes of friction have been devised for saturating steel bars with magnetism; instead of the simple mode just indicated, which goes by the name of the single touch, the two opposite poles of a magnet, bent into the form of a horse-shoe (95), may be brought down upon the centre of the bar

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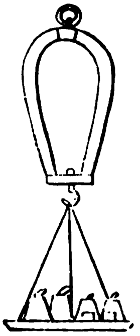
(95) This figure represents a magnet bent into the form of a horse-shoe; by which means the two poles are brought near to each other, and are better adapted to many experiments. When not in use, they are connected together by a piece of soft iron, which is called the *keeper*, by which their force is preserved unimpaired. The power of a magnet may be measured by suspending a scale-pan to the keeper, and loading it with weights till it becomes detached by their gravity.



to be magnetized, with the poles turned in a direction the reverse of that of the poles intended to be given to the bar, and then moved backwards and forwards along the surface; taking care to pass over each half of it an equal number of times, and repeating the same operation on the opposite side. This is called the double touch, and the bar becomes speedily and effectually magnetic.

§ 390. Great advantage is derived when two bars are to be magnetized, by disposing them in a parallelogram, in conjunction with connecting pieces of soft iron. The bars are touched in the way just described, so as to have their dissimilar poles opposed, and in proportion as they receive magnetism, these connecting pieces acquire a similar power, and by their reaction tend to exalt the intensity of the charge (96). Horse-shoe magnets, for the same reason, may be most efficaciously touched by connecting together their extremities with soft iron. In such a complete circuit, moreover, the power is preserved most securely by the reciprocal influence of the opposed forces, and magnets when out of use should be carefully protected in this manner. While such a circuit is closed, it will exert but a feeble influence upon any exterior body; but the *keeper*, as the soft iron bar is called, is retained in its position by a very powerful attraction. It is, however, found that the weight which it will support immediately after the process of magnetizing, is much greater than when the circuit is reclosed after having been once broken.

§ 391. Powerful magnetic batteries are constructed by uniting a number of horse-shoe magnets, laying them one over the other, with all their poles similarly disposed, and fastening them together in a copper case.

Mr. Scoresby has lately ascertained that great advantage arises from constructing magnets of thin plates of hard steel, separated from one another by very thin shavings of wood. A magnet thus formed of 196 plates, 15 inches long, and 1¼ inch wide, rendered an iron nail weighing 500 grains, magnetic by induction, at a distance of 11 inches, so that it supported another weighing 389 grains. It also sustained a nail weighing 194 grains through a slab of marble seven-eighths of an inch thick.

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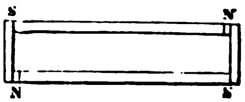
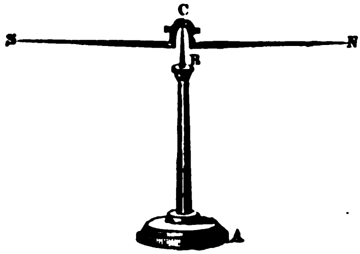
(96) This figure represents two bar magnets, with their opposite poles, N S, placed in juxta-position, and connected by means of their armatures of soft iron.



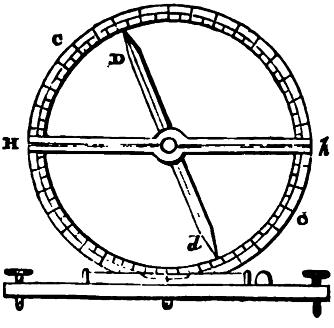
§ 392. The action of the earth upon a magnetic needle (97), may be compared to that of a large bar magnet upon it; and may be represented by the action of such a magnet passing nearly along the axis of a globe, the poles of which, however, do not exactly coincide with the poles of the earth's rotation. If a small magnetic needle, suspended so that it has freedom of motion in a vertical plane, be placed midway upon such a magnet or upon the equator of the globe, it will assume a horizontal position, with its poles directed to the dissimilar poles of the large bar.

The end of a needle, or bar, which directs itself towards the north pole of the earth, is, for convenience, generally distinguished by a mark, and is therefore best denominated the marked end. It is sometimes called the north end, or pole; but very improperly, as it manifests the opposite force to that which acts at the north terrestrial pole.

As the needle above mentioned is advanced towards one pole of the large magnet, the end which is directed towards that pole begins to dip or incline downwards, till at length it stands perpendicularly above it. Upon being gradually drawn back to its former position, it slowly recovers its horizontal direction; and upon being advanced towards the opposite pole, the same series of phenomena take place with the opposite end (98).



(97) This figure represents a convenient mode of supporting a needle for the purpose of indicating its direction. A is a stand in which is fixed an upright rod, of any substance but iron. The latter terminates in a point, which fits into a small agate cap at the centre of the needle, which is thus free to move with the least possible friction.



(98) The suspension of the dipping-needle is here shown. The needle is formed of a flat piece of steel, through the centre of which a small axis passes at right angles. It freely moves in circular holes, made in the horizontal bar, H *h*, which forms the diameter of the circle, C *c*, which is graduated for the purpose of showing the angle made by the needle with the horizon.

§ 393. Perfectly analogous phenomena of direction and dip take place under the influence of terrestrial magnetism, but the laws which govern them are of a more complicated nature. A needle freely suspended, out of the influence of any ferruginous mass, only remains in equilibrium when in the magnetic meridian; there are places where this line coincides with the terrestrial meridian, and in these a magnetic needle points to the true north. If, however, it be carried successively to different places on the earth's surface, its direction will be sometimes to the east, and sometimes to the west of north. It appears, from the latest researches, to be probable that there may be more than one magnetic pole in either hemisphere. According to the observations of M. Hansteen, there is one in Siberia, in longitude 102° east of Greenwich, and a little to the north of the 60th degree of latitude, and the other has been determined, by the observations of our late arctic navigators, to be about 96° 40′ W. longitude, and 70° 14′ N. latitude. The magnetic equator, moreover, does not exactly coincide with the terrestrial equator, but, from a discussion of all the observations, appears to be an irregular curve, inclined to it at an angle of about 12°, and crossing it in at least three points of longitude.

The direction of the needle varies even in the same place; in the beginning of the seventeenth century, the needle in London inclined a few degrees to the eastward of the true north; in 1659 it pointed exactly north; and after this the line of no variation began to travel slowly westward, and has now passed over to North America.

§ 394. The dip undergoes corresponding changes, though less considerable than those of the variation; and in London it has been found that there has been an annual diminution of about 3′ for the last fifty years. It is at present between 69° and 70°.

§ 395. The needle is also subject to diurnal variations of small amount; in our latitudes it moves slowly eastward during the forenoon, and returns to its mean position about ten in the evening. These variations doubtless depend upon diurnal changes of temperature.

Besides the variation and the dip, there is a third circumstance which is deserving attention, and that is the intensity of the force which obliges the needle to take up its position of equilibrium. This force varies greatly in different latitudes, and increases generally from the equator to the poles.

§ 396. For a long time the only known means of estimating the intensity of the magnetic forces, was to ascertain the weight which might be suspended from a magnet by means of a piece of soft iron. This of course is a very inaccurate operation; but Coulomb suggested two methods by which this important point may be determined with the greatest precision. The first of these is the torsion balance, the operation of which has been already described, and the second, the method of oscillations. This consists in counting the number of oscillations made by a magnetic needle in resuming its original position, under the influence of any magnetic force, when disturbed from its position of equilibrium. The movements of the needle are subject to the same laws which govern the oscillations of a pendulum acted on by the force of gravity; and it is a necessary consequence of these laws that the intensity of the force producing the oscillations is proportional to the square of the number of oscillations performed in a given time.

By these methods it has been determined that the forces, both of magnetical attraction and repulsion, are in inverse proportion to the squares of the distances of the active bodies.

§ 397. The earth, thus regarded as a magnet, is capable of acting by induction upon other bodies; and if in these latitudes we hold a bar of pure soft iron in the direction of the magnetic dip, the lower end will have the properties of the marked pole of a magnet, and the upper those of an unmarked pole, as may easily be ascertained by approaching them with a magnetic needle. That this state of polarity is only temporary, may be proved by reversing the bar, when the poles will be found in the same position as before. A bar of steel, or of hard iron, will become permanently magnetie by remaining long in the same position, and it commonly happens that the fire-irons, poker, and tongs, which usually incline against the grate, in a position not very different from that of the dip, become magnets.

§ 398. The communication of magnetism to a steel bar by this influence may be greatly expedited by causing it to vibrate strongly, as by striking it, when in the proper position, upon the end with a hammer. It may also be greatly increased by the inductive influence of other masses of iron in contact with it; notwithstanding the iron itself, which thus adds to the effect, derives its power also from the same source, namely, the magnetism of the earth. Thus a steel bar acquires a feeble magnetism by being hammered vertically when resting upon stone or pewter, but receives a considerable accession of power when subjected to the same degree of hammering while placed upon a parlour poker in a similar position. The power of a magnet is, in fact, always increased by the reaction of another body, in which it induces magnetism; and this property is made useful in *arming* (as it is termed) a natural loadstone, and thereby increasing its power. Two plates of very soft iron are provided, equal in breadth to the surfaces of the stone which include the poles, and a little longer; so that when applied to them, a portion of each plate projects beyond the loadstone. The armature is fixed on very firmly by wires, or an external case of any metal not susceptible of magnetism. The power of the stone is found to be thus very much augmented.

§ 399. As the mechanical vibration of the particles of a steel bar facilitates its reception of magnetic polarity, so will the diminution of its coercive power by the same means promote its return to the neutral state, and highly-charged magnets quickly lose their virtue by any concussion of their particles. A fall on the floor, rubbing with coarse powder for the purpose of polishing, and grinding, will all prove more or less injurious to their powers.

§ 400. The only substance, besides iron and its compounds, which has been found susceptible of magnetic polarity, of the kind which we have just been considering, is the metal, nickel; but there has been some difficulty in determining this point, from the small quantity of iron which is capable of conferring attractive powers upon other metals with which it may be alloyed. This in some instances is so small as to escape the detection of chemical analysis.

§ 401. The influence of heat upon magnetism is very remarkable. If a steel bar be heated to redness, and placed under magnetic induction, and then suddenly cooled, it will be found to have become strongly and permanently magnetic in a very short time. On the other hand, the application of heat to a magnet is invariably attended by a dissipation of its power. It is sensibly affected by the heat of boiling water; and a red heat totally destroys its magnetism. If the temperature, however, be raised only to 100, it loses much of its power during the operation, but recovers it again on becoming cool; but after it has been heated to redness, no part of its magnetism returns. The power of a magnet, moreover, increases as it becomes colder, to the utmost limit to which refrigeration can be carried.

At a white heat, iron appears to be totally insusceptible of any magnetic impression whatever, and a white-hot ball of iron may be brought close to a delicate magnetic needle, without at all disturbing its state of repose. Nickel loses its magnetic influence at a much lower temperature, and becomes totally indifferent when heated to 630° Fahrenheit.

§ 402. The phenomena of magnetism have been connected together by two hypotheses of exactly the same nature as those which have been applied to the analogous phenomena of electricity. The first, or that of Æpinus, refers them to the agency of a peculiar fluid, having properties very similar to those of the electric fluid in the hypothesis of Franklin, but which act only upon ferruginous bodies and Nickel. The particles of this fluid repel one another with a force which decreases as the distance increases, and they are attracted by the particles of iron with a force varying according to the same law. This hypothesis further requires the supposition that the particles of iron repel one another according to the same law.

The second hypothesis is exactly similar to the electric hypothesis of Du Fay, and is founded on the supposition of two magnetic fluids residing in the particles of iron, and incapable of quitting them. One of these imparts the northern, and the other the southern polarity, and they have been denominated respectively the *boreal* and *austral* fluids. The particles of each attract those of the other, but repel those of the same kind. When in combination with each other these fluids are inactive; each becoming active only when separate. The decomposition of the neutral fluid is effected by the inductive influence of either the one or the other when acting independently. Both hypotheses differ from the corresponding electrical assumptions by the necessary condition that the imponderable fluid cannot travel from particle to particle, but that the magnetic elements, or atomic portions of matter to which they are attached, are separated from each other by extremely small spaces, within which the displacements and motions of the magnetic fluids are restricted.

Either of these general views affords a sufficient basis for mathematical calculations which embrace all the leading facts of the science, but cannot for a moment be supposed to represent the real mechanism of the phenomena, especially since the inseparable connexion which has lately been proved to exist between the electrical and magnetical forces, into the nature of which it will be our future business to inquire.

§ 403. We are now, however, arrived at a point at which a more intimate knowledge of the properties of different kinds of matter, simple and compound, and of the laws of chemical combination and decomposition, is essential to our progress: and we must proceed to examine the character of *chemical affinity;* the laws which limit its action; and its connexion with the other forces which have already passed under our review.

CHEMICAL AFFINITY.

§ 404. Chemical affinity, or the highest degree of heterogeneous attraction, we have already recognised (§ 22) as the force which causes the dissimilar particles of different kinds of matter to combine together in the most intimate manner; forming compounds differing in all their essential qualities and actions from their constituent ingredients, and constituting, in fact, distinct species of matter.

The greater the original opposition of properties in bodies, the stronger appears to be this species of attraction between them. Heterogeneous adhesion seems to depend upon a certain similarity of nature. To effect the *solution* of a metal, another liquid metal, as mercury at ordinary temperature, or tin or zinc at higher degrees of heat, must be employed: inflammable liquids, as alcohol and ether, readily dissolve resins, fats, and other inflammable solids, which are not taken up by water; while water will dissolve salts and acids, which are but little acted upon by the mere adhesive force of the first-named substances. By the force of *affinity*, on the contrary, metallic bodies combine with non-metallic; acids with alkalies; combustible with non-combustible bodies.

The first questions which seem naturally to suggest themselves upon this statement are,—what are the simplest forms of matter? What is the chemical constitution of the familiar forms of matter with which we are surrounded? Are they simple or compound? What are the elements, or first ponderable principles of our globe?

§ 405. Now, in discussing these questions, we have something more formidable to deal with than mere ignorance:—namely, the strong prejudices of erroneous education. It requires no great advancement in classical knowledge to discover that the ancients considered that the four elements, out of which all other things in nature were compounded, were *earth*, *air*, *fire*, and *water*. The notion originated with a celebrated philosopher and good poet, named Empedocles, who flourished about four centuries before the

Christian era. His philosophical opinions were sung in verse by his contemporaries, and have been incorporated into the poetry of all succeeding ages; and have thus been invested with a charm and an authority well calculated to mislead the judgment, if not submitted to correction.

It is much to be feared that many highly-educated persons, persons, that is, thoroughly imbued with the taste and accomplished in all the literature of the ancients, are content with the meagre guesses made by them respecting the nature of those surrounding objects of paramount interest, upon which their very existence depends. The time of their youth has been devoted to pursuits with which the natural philosophy of the Greeks, or rather their crude speculations upon natural phenomena, are thoroughly interwoven; and in after-life they often want the time, or the inclination, to correct their careless observation of facts, and reckless assumption of abstract principles, by the sober results of the Baconian philosophy. But the error has been disseminated far beyond the sphere in which it originated, and has struck deep root in the general mind; its fibres having become entwined in the very texture of common language. Even our dictionaries of highest authority inform the inquirer, that the word element means "the first or constituent principle of any thing," and that the "four elements usually so called, are earth, fire, air, water, of which our world is composed*." We cannot commence our inquiry into the nature of chemical combination better than by applying the test of experiment to this popular and classical notion of the elements of all things.

Air and water, moreover, are almost necessarily present in all our operations, and it is of the utmost importance that we should become as early as possible acquainted with their properties.

Let us begin with air.

§ 406. The *mechanical* properties of the atmosphere in which we draw our breath, and on which our vital functions all depend, have been already examined (§ 42, *et seq.*): it is with its *chemical* properties that we are now to be engaged. And first, let us inquire whether air be capable of resolution into parts of dissimilar nature and properties by the arts of chemistry.

Now, the only means at our disposal for effecting the decomposition of bodies, compounded under the force of affinity, is a

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[*] TODD'S JOHNSON. This illustration of the word element, still holds its place even in the admirable *New Dictionary of the English Language*, of Mr. Charles Richardson. The French lexicographers have long since ceased to propagate error.

higher degree of the same attraction in some other body for one of their component parts, assisted sometimes by the concurrent action of other forces. The process which goes by the name of *Elective Affinity*, is a play of forces of exactly the same nature as that which has already been described in the case of the subordinate force of heterogeneous adhesion (§ 102). It has been exemplified in the decomposition of the combination of nitric acid with copper; when a blade of iron immersed into the solution became covered with metallic copper (§ 22). The affinity of the iron for the nitric acid was greater than that of copper; the iron therefore combined with the acid, and the copper was disengaged.

To ascertain, therefore, whether air be of an elementary or compound nature, we must subject it to the action of some of the most powerful agents; and observe whether they are able to abstract any portion of its substance to the exclusion of another portion.

§ 407. One of the most energetic processes with which we are familiarly acquainted, is that of *combustion;* and common experience ought to be enough to convince a careful observer that it is dependent upon the air. A simple experiment with the air-pump will satisfy any one that it is essential to it; for any burning body placed under the receiver will be extinguished by the exhaustion of the air.

Most persons are also aware that a lighted taper will be extinguished, after burning a short time, in a portion of air confined in a bell-glass standing over water. If a more accurate experiment be made by igniting a piece of another combustible body, phosphorus, under a receiver whose edges are ground so as to render it air-tight when standing on a brass plate, it will burn for some time; white flocks of a new species of matter will form in the air, and fall upon the plate like snow, and it will soon be extinguished. Upon opening the receiver under water, after it has cooled down to its original temperature, a quantity of water will rush in and fill one-fifth part of the capacity of the receiver. The quantity of air consumed will never exceed or fall short of this amount, if the experiment be conducted with sufficient accuracy. The residual four-fifths of the air, after washing, will, upon examination, be found possessed of very different properties from those of the original quantity.

§ 408. In the first place its specific gravity will be different; 100 cubic inches at mean pressure and temperature, will only weigh 30.15 grains, instead of 31 grains. In the second place it will not support combustion; phosphorus in a state of intense inflammation will be instantly extinguished by it: and lastly, it will not support life; insects, or other small animals, will soon expire if confined in it. If the experiment be made with a proper regard to quantities, it will be found that the weight of the white matter formed during the process will be exactly equal to the weight of the deficient air, added to the weight of the phosphorus consumed. This, then, is clearly a case of elective attraction: the phosphorus has taken a something from the air, with which it has combined and produced a new form of matter, to the exclusion of another portion with which it refuses to unite.

The residual air is one of our *chemical elements;* meaning no more by the expression than that, in the present state of science, art is incapable of resolving it into more simple principles. The chemist of the present day has learnt diffidence from the failure of his predecessors, and no longer affirms that the substances which resist his powers of decomposition are the real elements of nature; but, on the contrary, holds it as extremely probable that, as science advances, many undecompounded substances may be resolved into simpler forms of matter. Till experiment, however, shall have shown this to be possible, it is not contrary to the principles of the inductive philosophy to consider them as elementary.

This gaseous body is sometimes called *Azote*, from its noxious influence upon life; but more commonly *Nitrogen*, from its entering into the composition of nitre. It was first distinguished by Professor Rutherford of Edinburgh, in 1772.

§ 409. But what is the substance which has entered into combination with the phosphorus, and which constituted a portion of the original air under examination? To enable us to answer this question, we must change our agent; for the attraction of the phosphorus is so strong as to render it very difficult to detach it from the new compound. Many other substances are capable of effecting the separation of the air; some with the evolution of light and heat, others with less energetic action. Thus, if an amalgam, or solution, of lead in mercury be agitated with a portion of atmospheric air for some time, exactly the same proportion of the mixture will be absorbed as in the case of the combustion of the phosphorus, and the residual azote will be very pure. If a portion of mercury again be heated to nearly its boiling point in air, chemical combination will take place between it and the same proportion, and the mercury will lose its metallic character, and will be converted into a brilliant, red, crystalline substance, increasing its weight eight per cent, If some of this red compound be placed in a small retort, the beak of which is dipped under the edge of a bell-glass, filled with water, and standing upon the shelf of a pneumatic trough, and it be then exposed to a low red heat, it will be decomposed; gaseous matter will rise into the glass and displace the water, and drops of metallic mercury will be condensed in the neck of the apparatus. One hundred and eight parts by weight will yield eight parts of the air; which is the same as it had abstracted from the atmosphere in the previous process, at a somewhat lower degree of temperature.

Like the azote it is colourless and inodorous, and possesses all the mechanical properties of common air. Its specific gravity, however, is higher; 100 cubic inches, weighing 34.45 grains. If we examine it by means of combustible bodies, we shall find that it supports combustion with much greater energy than common air. The flame of a taper becomes much larger and more brilliant when burning in it; and when blown out, if the smallest spark remain upon the wick, it will burst into flame upon being immersed into it. Phosphorus burns in it with a brilliancy which is quite intolerable to the eye, and forms the same snow-white compound which is produced by its less-vivid combustion in common air. Ignited charcoal also produces most brilliant scintillations when introduced into it; and if we attach a morsel of glowing tinder to the end of a bunch of twisted iron wire, and plunge it into a jar of the gas, the metal will combine with it, and present a most striking and beautiful display of fire. Other metals, such as potassium and zinc, when previously heated, also enter into combination with the gas, with a copious disengagement of light and heat.

It will support animal life; and animals confined in it will live longer than in an equal bulk of common air. Hence it has been called *vital air;* and, for reasons which will be hereafter explained, *oxygen gas.* This is another of those substances which resist the divellent force of affinity, and which the chemist, therefore, regards as elementary. It was discovered by Dr. Priestley, in the year 1774, who obtained it from the red compound of mercury, which we have described, and which went by the name of *precipitate per se.*

§ 410. This gas may be obtained from many other analogous compounds, such as red lead; but a native compound of a peculiar metal, named *manganese*, with oxygen, is chiefly employed in the large way. Certain saline bodies also, as *nitre* and *chlorate of potassa*, hold oxygen loosely combined, and yield it in abundance when heated. The latter salt is chiefly employed when it is required to be perfectly pure (99).

§ 411. The influence of heat in these operations is worthy of remark. In most instances we find that a considerable elevation of temperature, in some even to incandescence, is necessary to determine the combination which a further increase of heat is sufficient to decompose. The difference arises from the unequal exaltation of two distinct and antagonist forces. It may probably be laid down as a general proposition, that heat increases the energy of chemical affinity; but it also increases the elastic force of gases. Mercury will not enter into combination with oxygen, to form the red precipitate, till the power of attraction between the two bodies is called into action by a temperature of about 600° Fahrenheit; at this degree the affinity is strong enough to coerce the elasticity of the gas, and it enters into the constitution of the new solid. An augmentation of temperature to about 900° Fahrenheit, restores the advantage to the elastic force, and the gas escapes from the coercion of its affinity for the metal.

§ 412. Let us now examine the process of combustion a little more closely. Common observation suggests that it is nothing

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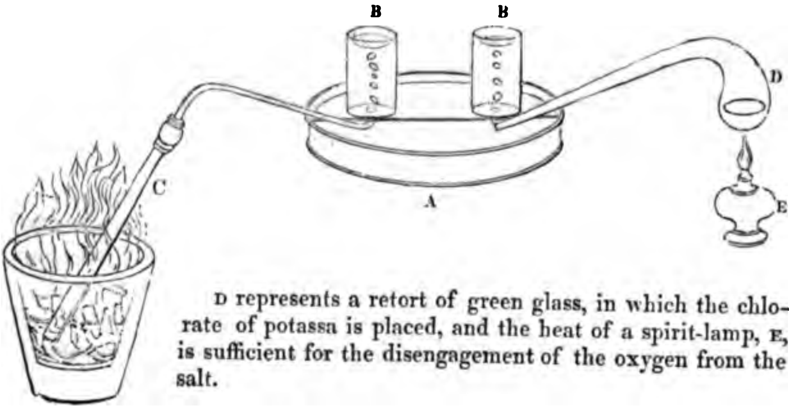
(99) The apparatus for the collection of oxygen gas from per-oxide of manganese and chlorate of potassa is here sketched. A is a water bath, upon the shelf of which stand the two air jars, B and B. C represents an iron gun-barrel, closed at the bottom, and fitted at the top with a flexible metallic tube, passing under the mouth of one of the jars. The oxide of manganese is placed in this barrel, and exposed to a red heat.



D represents a retort of green glass, in which the chlorate of potassa is placed, and the heat of a spirit-lamp, E, is sufficient for the disengagement of the oxygen from the salt.

but a process of destruction; to ordinary eyes the combustible seems to vanish, and nothing to remain but an inconsiderable quantity of what are called *ashes*, which are the usual residue of burning bodies. Annihilation enters into the common idea of combustion; and to say that a body is burnt, is generally a full, satisfactory, and sufficient account of its disposal. But such destruction is unknown in the economy of nature; and we have no reason to suppose that since the fiat of the Creator went forth, a particle of matter has ever ceased to be. Combustion, in the largest and most scientific meaning of the term, is the combination of any two dissimilar bodies with the extrication of light and heat; and the products of combustion invariably contain as much ponderable matter as the two active substances. The new forms of matter produced often assume the aëriform condition, and pass off in an invisible state, and therefore escape common observation: but when collected, nothing of the original weight will be found wanting.

Hence we conclude that *fire* cannot be an element, or one of the simple forms of ponderable substances.

The term combustion is ordinarily restricted to the combination of substances with oxygen; and bodies are denominated *combustibles* which are capable of uniting with the oxygen of the atmosphere, with the evolution of light and heat.

§ 413. The products of combustion in oxygen, or the compounds of oxygen, constitute three great classes of *acids*, *alkalies*, *and oxides*, which it is important to distinguish; and which may be illustrated by the results of the experiments which we have already described.

The snow-white compound of phosphorus is soluble in water, intensely sour, and changes the colour of blue vegetables to red: characters which distinguish the class of acids. It was formerly supposed, from a too-hasty generalization of facts, that oxygen entered into the constitution of all acids; that it was, in short, the principle of acidification; and hence, Lavoisier, the propounder of the hypothesis, conferred upon it its name, which signifies the generator of acids. The error has been corrected, but the name retained.

The compound of the metal potassium and oxygen is also soluble in water, possesses a hot, acrid, bitter, soapy taste, and changes the colour of blue vegetables to green, and yellow to brown. These are the characters of the class of alkalies.

Acids and alkalies are also reciprocally characterized by entering into secondary combination with each other by which their more active properties are neutralized. If a solution of an acid in water, which has been reddened with some vegetable blue colouring matter, be carefully poured into a solution of an alkali rendered green by the same colour, at a particular point the mixture will have its blue colour restored, when it will be found to be neither acid nor alkaline to the taste, and if the water be evaporated, a solid mass will be obtained, possessing a cooling saline taste, and presenting a species of matter utterly differing from its two more active ingredients.

The product of the combustion of iron is of a friable texture, insoluble in water, tasteless, and without action upon vegetable colours. These negative characters distinguish the class of oxides; which, however, are mostly capable of neutralizing and entering into combination with acids, and forming salts with them.

§ 414. The process of pulling a substance to pieces, of *unloosing* the connexion of its constituent parts, in order to examine it piecemeal, as we have performed it upon atmospheric air, is called *analysis*. The process of *putting together* again the same ingredients, so as to reproduce the body analyzed, is called *synthesis*; and when one of these processes confirms the other, the proof of the constitution of the body is the completest which chemistry can afford, and wants nothing of the certainty of mathematical demonstration. The science, however, is very far from having attained to this degree of perfection, in many cases where it would be most desirable.

§ 415. If we add one measure of oxygen gas to four equal measures of nitrogen, we shall obtain a mixture capable of supporting combustion, and maintaining animal life in the same perfect manner as atmospheric air. The union of the two is effected, not by the force of chemical affinity, but by that of heterogeneous adhesion, concurring with the elasticity and self-repulsion of the homogeneous particles. We have seen that there is no limit to such combinations (§ 98), and therefore the invariable uniformity of the atmospheric mixture is one of the most astonishing facts with which chemistry has made us acquainted.

Air has been examined, as has been already stated, (§ 101,) by the most expert analysts, from the most dissimilar situations which it has been possible to select, and no variation has been found in the proportions of its fundamental ingredients. When we consider the processes of deterioration and change which are always going on within it, its perpetual consumption and renewal forms one of the greatest wonders, where all, indeed, is admirable. All the most active properties of the atmosphere are referrible to the oxygen which it contains, and are those of that body diluted. Without oxygen no animal could live; in pure oxygen they would live, if the expression may be allowed, too rapidly: just as a candle would burn too rapidly; and as every case of combustion would be one of conflagration, all the vital functions would be increased to a morbid excess, and fever and death would ensue.

§ 416. Had it been ordained that the union of oxygen and nitrogen in the atmosphere should depend upon the higher attraction of chemical affinity, it is easy to perceive that the present beneficial results could not have ensued. The divellent force must have been proportionately increased, and the tranquil process of breathing must have been changed for one of violence and strong exertion. The new and noxious products of the fixed combinations of the elements would have accumulated around the spots frequented by animals, instead of being diffused with rapidity throughout the general mass, and replaced by fresh vital air, according to the laws which we formerly examined (§ 100).

§ 417. But we must not yet part from this wonderfully-constituted fluid: our process of analysis is not complete, and our synthesis has produced an atmosphere, indeed, which would answer the purposes of animal respiration, but vegetables would not thrive under its influence. Vegetable respiration could not be maintained by it. We must seek further for some principle which has yet escaped our detection.

Common experience has made most persons acquainted with *lime:* it is an alkaline substance, and partially soluble in water. Its solution is colourless, transparent, possesses a hot, bitter taste, and turns the yellow colour of turmeric brown. When this solution is exposed to the air, it slowly becomes turbid; its alkaline properties are neutralized, and it deposits a white powder. Reasoning from the analogy of what we already know of alkaline and acid bodies, we are led at once to suppose, that the lime in this process has abstracted something from the atmosphere of an acid nature; and that the white powder is the product of the combination. If we collect a sufficient quantity, and place it in a platinum tube closed at one end, and bent into the form of a retort, and apply a strong heat, we may collect a quantity of gaseous matter from it over mercury, and alkaline lime will remain in the tube. Or, instead of decomposing the compound by heat, we may effect its decomposition by elective affinity; and upon the supposition of its containing an acid, the addition of a stronger acid will occasion an effervescence, the product of which may be collected.

§ 418. Now, what is this gaseous matter which we have again abstracted from the atmosphere? and does it differ from those already obtained? If we examine it, like the others, we shall find that it will not support the combustion of a taper, or of phosphorus, and that it is instantly destructive of animal life. That it is not, however, azote, is proved by its high specific gravity; for 100 cubic inches will weigh 47.37 grains; and it may be poured like water from one vessel into another, in which it will displace the common air by its density. It, moreover, neutralizes the alkaline properties of lime, reddens the blue colour of litmus, and renders lime-water instantly turbid.

§ 419. The next question is, can it be resolved into any simpler form of matter? To ascertain this, we must try the action of energetic substances, amongst which potassium ranks very high. If we heat a clean piece of this metal, and introduce it into a jar of the gas, we shall find that it will burn in it, and at the same time become covered with a black matter, which a close examination will prove to be *charcoal*. The product of the combustion will be the same alkaline substance which was produced by the action of the same metal upon oxygen, or atmospheric air.

From the results of these analytical experiments, we conclude that, in addition to nitrogen and oxygen, atmospheric air contains a small portion of a third gaseous body, which is a compound of charcoal and oxygen: and we may confirm our conclusion by synthesis; for if we examine the product of the combustion of charcoal in oxygen, we shall find it to be a colourless gas which neutralizes lime-water, and produces a precipitate which dissolves with effervescence in vinegar, or any other acid.

This compound was discovered by Dr. Black, in 1757, who called it *fixed air*, from its being fixed in limestone from which he first obtained it. It has since been called *carbonic acid*, from the Latin name for charcoal.

§ 420. Charcoal, or *carbon*, ranks amongst the undecompounded bodies. Although but rarely met with pure and uncombined, its various compounds are more generally and abundantly distributed than those of any other substance, and it may be said to form the basis of the whole organic creation. In its crystalline state, its cohesion is very great, and it constitutes the hardest substance in nature, the *diamond;* it exists in various gradations between this state and that of a soft, disintegrated, black powder, which adheres to and stains the fingers. It exemplifies the opposition which the force of cohesion is capable of offering to chemical affinity; for in its disintegrated state it readily kindles and burns in oxygen, and is commonly employed as *tinder* for catching a light from ignited particles of steel; whereas, in the state of diamond, it requires the strongest heat which art can produce to ignite it, and sufficiently to exalt its affinity to enable it to burn.

The use of charcoal, as a fuel, is well known. For this purpose it is prepared by forming billets of wood into conical piles, which, being covered with earth, are ignited and suffered to burn with a regulated access of air, by which the more volatile ingredients are burnt and driven off, whilst the solid charcoal remains. For nicer purposes of the arts, it is procured by submitting the wood to a red heat in a distillatory apparatus consisting of iron cylinders, from which the gaseous or volatile matters are allowed to escape through properly-arranged tubes.

Charcoal is a black, inodorous, insipid, brittle substance, and, as we have already seen, an excellent conductor of electricity. It undergoes no change from the combined action of air and moisture at common temperatures, but is readily combustible in oxygen gas.

§ 421. Carbonic acid is produced by the respiration of animals, as may be proved by passing the air from the lungs through lime-water, which will be instantly precipitated by it; and by the extinction of a taper in a jar of air which has been breathed two or three times through a tube properly disposed for the purpose.

Vegetables, on the other hand, in full vigour, decompose the compound, absorb the charcoal, and disengage the oxygen; and a sprig or two of fresh mint, in day-light, will perfectly restore air which has been contaminated by animal respiration. We here have indicated to us a part, at least, of the compensating means by which the atmosphere is kept in a perfect state of adaptation to its beneficial purposes.

§ 422. There is yet another constituent of the atmosphere which is always present in variable proportions, and that is *water* in the state of vapour, and it may always be rendered visible, and its quantity estimated, by the refrigeration of a cold body, as we have already pointed out (§ 197). This ingredient of the mixture is alike beneficial to animal and vegetable life, and without it the surface of the earth would present nothing but the sterile aridity of a desert.

Both the carbonic acid and the vapour are variable ingredients, but the average quantities of each, in 1000 parts, may be approximatively stated as follows:—

Azote	788
Oxygen	197
Steam	14
Carbonic acid	1
	1000

§ 423. Thus, then, we have demolished the pretensions of our first classical element, air, to rank amongst the "first or constituent principles of things," and have established three chemical elements in its stead; namely, azote, oxygen, and carbon. The two first have never yet had their particles brought within the verge of cohesive attraction, and have resisted all attempts to liquefy them; while the utmost powers of heat have been applied in vain to destroy the cohesion of the last, or to bring it into the state of vapour.

Amongst the ingredients of the atmosphere, we have also found a second classical element, *water*, into the pretensions of which to the elementary character we must proceed to inquire.

§ 424. We must attempt its analysis by the means which we have already applied successfully in similar cases. If we throw a piece of the metal potassium upon water, it will float upon it: intense action will take place; a flame will burst forth from the point of contact, and the metal will disappear. After this operation we shall find that the water has become strongly alkaline, and upon evaporation we shall obtain a white solid, exactly similar to that which was obtained by burning potassium in common air or oxygen. We infer, then, that the metal has taken oxygen from the water, and that the compound has been dissolved as it was formed. But if so, what is the substance with which the oxygen was combined? To determine this, we must operate more carefully, that nothing may escape in the elastic form; and, as the action is violent, we must proceed with caution. For this purpose we may fill a strong narrow glass jar with water, and invert it upon the water-trough, and wrapping a piece of potassium closely in paper, or placing it in a small glass tube closed at one end and carefully covering it with fine sand, slip it dexterously under the edge of the jar. The metal is momentarily protected from the water, which, however, soon reaches it; a smart concussion takes place, and a quantity of gaseous matter rises to the top of the jar. Upon reversing the jar, and presenting a lighted taper to the gas, we shall find that it will burn with flame; that is, that it enters into combination with the oxygen of the air, with the extrication of light and heat.

§ 425. This decomposition of water may be accomplished by less costly means than potassium, making use of the elective affinity of more common metals for oxygen.

Iron may be employed for the purpose; but it will be necessary to exalt its affinity by heat. For this purpose, turnings of iron may be put into in a gun-barrel placed across a furnace, one end of which is connected with a small water-boiler, and the other with a bent tube passing under the edge of a jar upon the pneumatic trough. Upon heating the iron to redness, and allowing the steam of boiling water to pass over it, abundance of inflammable air may be collected; and the same compound which is formed by the combustion of iron wire in oxygen may be extricated from the barrel (100).

§ 426. The affinity of zinc may also be had recourse to; and that at ordinary temperatures. But for this purpose it is necessary to remove the compound of the zinc and oxygen as it forms, which would otherwise incrust the surface, and put an end to the process. This oxide is not soluble in water, like the similar compound of potassium; but by the addition of a little sulphuric acid, or oil of vitriol, it will form a secondary compound, which will instantly be dissolved. Large quantities of inflammable air may thus be readily and economically procured.

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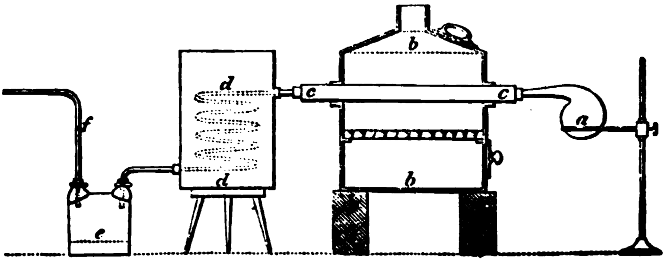
(100) *a* represents a glass retort containing a little water, which may be raised in steam by the application of a lamp. The steam then traverses the tube, *c c*, in which is placed some iron wire heated to redness by the furnace, *b b*. The iron combines with the oxygen of the water, and the inflammable gas passes into the worm, *d d*, which is kept cool by the water in the tub. Here any uncombined steam, with which it may be mixed, is condensed, and the water drops into the vessel, *c*, placed for its reception. The gas ultimately passes out of the pipe, *f*, and may be burned or collected in the usual way.



The compound of oxygen and zinc, again, may be separated from the acid by elective affinity; for the addition of some of the alkaline solution of the compound of potassium and oxygen will abstract the acid and precipitate the oxide (101).

§ 427. The inflammable air, which has been named *hydrogen* because it enters into the constitution of water, burns, as we have seen, in common air, but extinguishes flame, as may be ascertained by plunging a lighted taper into it. When a mixture is made of two parts of common air and one of hydrogen, or of two parts of hydrogen with one of oxygen, the combination, which proceeds silently when a moderate jet of the inflamed gas issues quietly into the atmosphere, takes place at once throughout the mass with a strong detonation, owing to the mutual percussion of the particles of the highly-expanded air returning into the vacuum which is produced. When the mixture is merely confined by a film of water in a soap-bubble, the explosion is sharp and deafening.

§ 428. If a current of hydrogen be inflamed when issuing from a small aperture, and a tube be held over the flame, a musical tone will be produced, varying in its pitch with the length of the tube. These sounds depend upon a series of little explosions which succeed one another with sufficient regularity and rapidity to produce a continuous sound (§ 51). By the strong draught which takes place through the axis of the tube, the air and the hydrogen are

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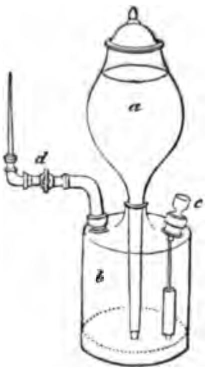
(101) This figure represents a convenient apparatus for the generation of hydrogen gas in small quantities from zinc. *a* is a funnel-shaped glass vessel, the lower extremity of which dips into the dilute sulphuric acid contained in the bottle, *b*. A bent tube proceeds from the upper end of the bottle, which is furnished with a stop-cock at *d*, and terminates in a narrow jet. From the aperture *c*, which may be closed with a ground stopper, a piece of zinc is suspended in the acid, and the hydrogen which is disengaged rises to the top of the bottle, and forces the liquid into the upper vessel, the pressure of which will drive the inflammable gas through the pipe *d*, whenever the stop-cock is opened. As the gas passes out, the liquid will descend again into the bottle, and renew the disengagement of the gas; and the process will go on till the acid becomes saturated with the oxide of zinc.



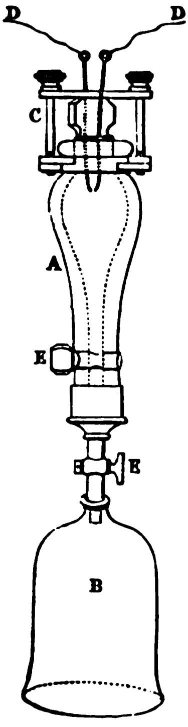
made to form portions of exploding mixtures, which are fired by the contiguous burning parts. Sometimes the draught becomes so strong as to blow out the flame.

§ 429. We are so habituated to speak of the process of combustion, with reference to our atmosphere, and to name bodies *combustible* which enter into combination with its oxygen, that a prejudice is likely to arise from it with regard to the classification of objects. We constantly see a stream of hydrogen burning in common air, and we call the first a *combustible;* and the second, a *supporter of combustion;* but by throwing a jet of oxygen into an atmosphere of hydrogen contained in a large bell-jar, through an aperture at its upper end, when the latter is burning, the flame will be carried down into the body of the jar, and the oxygen will continue to burn in the hydrogen as it issues from the jet. In this case the oxygen may be said to be the combustible, and the hydrogen the supporter. The simple statement of the fact in both cases is, that oxygen and hydrogen combine together, and combustion—that is, the disengagement of light and heat—is the consequence.

§ 430. Hydrogen gas is speedily fatal to animal life when taken pure into the lungs, but may be respired when mixed with common air without much injury: it is the lightest form of ponderable matter, and 100 cubic inches only weigh 2.15 grains. Hence its application to aërostation. A thin bladder, or soap-bubble, filled with it rises in the air with rapidity, for the same reason that a cork rises through water. A balloon formed of a sphere of ten feet diameter would contain about 32½ lbs. of atmospheric air, but the same bulk of hydrogen would only weigh two pounds; hence, with an ascensional force of two pounds and a half, it would rise in the air with a weight of twenty-eight pounds attached to it.

Hydrogen must be deemed an element, because it has resisted all attempts to decompose it. No degree of cold or pressure has yet been found sufficient to reduce it to the liquid state. Its combustibility was known in the beginning of the eighteenth century, when it was often exhibited as a curiosity; but its nature and properties were first properly investigated by Mr. Cavendish, in 1776.

§ 431. Synthesis will confirm this analysis of water; for if we carefully collect the product of the combustion of hydrogen and oxygen gases, we shall find the water in weight exactly equal to that of the gases consumed. The experiment requires some caution, on account of the violence of the action, but may be easily performed in the following manner.—Provide a very strong glass tube, closed at one end, and fitted at the other with a brass cap and stop-cock, strongly fixed with cement; two small holes must be drilled in the upper part of this tube, into which two wires must be cemented, the points of which nearly touch on the inside. Let a mixture of very pure oxygen and hydrogen gases be very accurately made, in the proportion of one volume of the former to two of the latter, in a jar fitted with a stop-cock, to which the cock of the tube may be screwed; extract the air from the tube, by means of the air-pump; fill it with the mixture, and again exhaust it; and once more fill it with the mixture, and carefully close the stop-cock; pass an electric spark between the wires, and the gases in the tube will explode with a bright flash, but silently, on account of the connexion with the surrounding air being cut off. Allow the tube to cool, and, upon opening the cocks, a fresh portion of the gases will rush in which will be equal to the first quantity, provided the mixture has been accurately made, and the common air perfectly extracted. This portion again may be detonated, and the process continued till a strong dew forms upon the glass, and runs down in drops of liquid, which, upon examination, will prove to be pure water (102). The products of the combustion of hydrogen in atmospheric air may also be collected in large quantities by a proper refrigerator.



§ 432. We have already adverted to the great heat which is generated by the combustion of oxygen and hydrogen; it is the most intense which art can produce. If a compound jet be constructed of two concentric tubes, and the outer one be connected with a reservoir of hydrogen, and the current inflamed, and a stream of oxygen be thrown into the flame, by means of the interior tube connected with a reservoir of oxygen, the heat may be conveniently applied to the fusion of the most refractory substances; and there is, probably, nothing which can completely resist its power.

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(102) A is a strong glass vessel, fitted with a glass cock, accurately ground. At the upper end it is provided with a glass stopper, firmly screwed down, and secured by the brass collar and screws, C. Two platinum wires pass through this glass cock, and approach one another in the interior, without touching. This vessel may be exhausted by the air-pump, and screwed upon the bell-glass, B, filled with the proper mixture of oxygen and hydrogen. When the cocks, E E, are opened, the air in the jar will, of course, rush into the vacuum in A, and then, after carefully closing the stop-cocks, an electrical spark may be passed between the wires, and the gases will combine with a vivid flash of light.

§ 433. Such are the experiments by which the opinion of the ancients was upset, that water is one of the four elements of the material world, an opinion which remained unquestioned from the time of Aristotle to that of Cavendish.

§ 434. Having thus disposed of air, fire, and water, it will forward our design of obtaining some preliminary acquaintance with the properties of different species of matter, if we examine the fourth classical element, EARTH, before we establish the laws which limit the action of chemical affinity, and of the various compositions and decompositions which depend upon it. But here a difficulty occurs in fixing the meaning of the word. Every one attaches a definite idea to the terms air, water, and fire, and they have doubtless borne the same meaning in all ages of the world; but the terms *earth*, *earthy body*, are much more vague and indefinite. At the same time, an earth is commonly understood to be a dull, solid, opaque, friable substance, without lustre, and not disposed to burn or take fire; and is thus distinguished from metals on the one hand, and from carbon and other inflammable substances, on the other.

According to common experience, the greatest part of combustible substances leave, when they are burnt, an earthy residue which is generally called their *ashes*. This earthy residue is very frequently the result of the combination of some metal with oxygen; —it is an oxide. Wood, and other vegetable substances grown at a distance from the sea, when burnt, leave an abundance of such ashes, which are valuable articles of commerce, and known by the name of *potashes*. They are alkaline, and the soluble matter which may be obtained from them, when purified and deprived of carbonic acid, by the elective affinity of lime, is exactly the same as that which is obtained by the oxidation of the metal potassium, and is called *potassa*.

The earthy residue of the combustion of sea-weeds affords another alkaline substance, whose properties very much resemble potassa, to which the name of *soda* has been given. It is a combination of the metal sodium (which is analogous to potassium) with oxygen.

There are other substances again, which occur naturally as earths, such as clay and sand. On the other hand, whenever we burn the metals, or cause them to combine with oxygen by less energetic processes, we obtain earthy products which differ in colour; and of these the combinations of iron, copper, zinc, antimony, may be taken as examples. The oxides, in short, used formerly to be known by the name of the *earths of the metals*. They frequently occur in the native state, and constitute the ores from which the metals may be obtained.

§ 435. The processes of reduction are all instances of elective attraction; and the affinities which are applied to this purpose are those of hydrogen and carbon, most frequently assisted by a high temperature. The metals potassium and sodium have the highest affinity for oxygen, and therefore require the most energetic means for their extraction. It is effected by causing a combination of their oxides with water, obtained from the ashes of vegetables as we have just stated, carefully purified, to pass in a melted state over clean iron turnings heated to whiteness in a gun-barrel properly bent and disposed for the purpose. A portion of hydrogen gas is probably first disengaged from the decomposition of the water, and reacting upon the potassa or soda (as the oxides of potassium and sodium are respectively called), combines with its oxygen, and sets the metals free. These are carefully introduced into some liquid (naphtha) which contains no oxygen in its composition, and are thus preserved (103).

§ 436. The earths, or oxides, of other metals, may also be reduced by placing them in tubes heated to redness, and passing a current of hydrogen over them; but the most common process is, to mix them with charcoal as the deoxidating agent, and expose them to a strong heat.

In processes of manufacture, such as those of iron and tin, the ores (which are called iron-stone and tin-stone) are mixed with the fuel, and ignited in properly-constructed furnaces, in the bottoms of which the metals are collected in the fused state, and are thence suffered to run into proper moulds placed for their reception.

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(103) The apparatus for the production of potassium is here represented. The upper figure exhibits the gun-barrel bent into the

§ 437. A better instance cannot be adduced of the influence of prejudice upon the mind, and of the particular ancient prejudice with regard to the elements which we are engaged in combating by the experimental philosophy, than the science of the reduction of the metals affords. Even so late as the end of the seventeenth century, an eminent German philosopher, Stahl, invented an hypothesis to explain the process of combustion, which was long celebrated by the name of the *Phlogistic Theory.* In it the elementary nature of the *earths* was taken for granted, and the metals were supposed to be compounds of these simple substances, with an universal principle of inflammability, or fire, to which was given the name of *phlogiston.* It professed to be founded upon the basis of experiment. When zinc was heated to redness it burnt with a brilliant flame, and was converted into a white earth; hence it was concluded that zinc consists of this earth and phlogiston. Again, the earth was heated with charcoal, or some other body abounding in the imaginary phlogiston,

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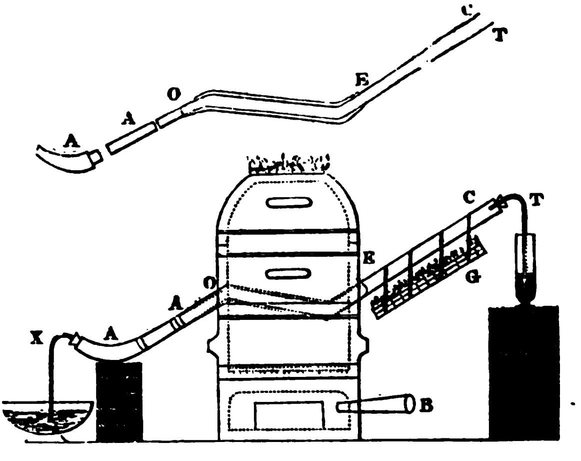
proper form, and covered from O to E with fire-clay, to protect it from the fire. Pieces of fused potassa are placed in the inclined part, from E to C, and the iron turnings occupy the space from E to O. A A is a copper tube and small receiver, which are fitted by grinding to the extremity, O.



In the lower figure the tube is seen in its proper position in the furnace. Each extremity is closed by bent tubes, X and T, dipping under the surface of mercury. The copper vessel is kept cool by wet cloths, and the potassa is fused by red-hot charcoal, in the tray, G. The fire is urged to the utmost by a good double bellows entering the ash-pot at B.

with which it combined, and the metal was reproduced. When it was observed that the body burning always increased in weight, there were not wanting those who went the whole length of ascribing *lightness* as a quality to phlogiston, by parting with which the burnt body became heavier. Notwithstanding this difficulty, and the necessary presence of air to the combustion, the hypothesis was immediately embraced by the generality of chemists, and maintained its ascendency for more than fifty years, until shaken and upset by the arguments of Lavoisier.

§ 438. The metals constitute a well-known class of substances, distinguished from other substances by characters which every one recognises. The class is numerous, but none of them has been resolved into more simple forms of matter, and they are therefore considered to be chemical elements.

The metallic character forms the first ground for classification, and the elements are divided, with reference to it, into *metallic* and *non-metallic*. Although popularly recognised, it is difficult to define with accuracy. With one exception, namely quicksilver, they are all solid at ordinary temperatures, but are capable of liquefaction, and even volatilization, at different high degrees of heat. Their most striking property is their lustre, which is so remarkable as to be known by the name of the *metallic lustre ;* it is at once recognised, but difficult to describe. It is dependent upon their action upon light, and made up of opacity and reflexion.

They possess in different degrees a peculiar tenacity, which in its greatest perfection renders them *malleable* and *ductile*, or capable of being extended under the hammer, and drawn into wire, properties which belong to no other species of matter. One grain of gold may be extended so as cover fifty-two square inches of surface, and yet have its lustre unimpaired : and platinum wire has been obtained the $\frac{1}{30000}$th of an inch in diameter, which is invisible, except under particular circumstances of illumination. There are, however, various gradations of this property, which end in brittleness; and antimony may easily be pounded in a mortar.

Metals also differ in hardness, some being capable of scratching glass, as titanium and iron; others, on the contrary, may be cut by the finger-nail, as lead, potassium, and sodium. Their points of fusion vary between – 40°, the freezing-point of mercury, and the melting-point of platinum, which is a little beyond 3280°.

A high specific gravity was one of their most marked characteristics, till the recent discovery of the metals of the alkalies; and so intimately, till then, was the metallic lustre associated, in the minds even of the well-informed, with great weight, that when a piece of potassium was placed by Sir H. Davy, for the first time, in the hand of an eminent teacher of chemistry, in admiring its perfect metallic characters he poised it upon his finger, and exclaimed, "how heavy!" This prejudice was only removed by seeing it float upon water.

Platinum is the densest form of matter with which we are acquainted, and its specific gravity is 21.5. The lightest metal is potassium, and its specific gravity is 0.865.

We have already found that the metals are the best conductors of heat, and one of their most marked physical characters is the perfect way in which they conduct electricity. The only substance which can be compared with them in this property is charcoal, and this is inferior to iron, the worst of the class.

They are chemically distinguished by forming saline bases (or substances capable of neutralizing and entering into secondary union with acids,) with oxygen. Gold and arsenic are the only exceptions to this rule. The affinity of the metals for oxygen varies very greatly between those of gold and platinum, whose oxides may be decomposed by the slightest forces, and that of potassium, which will attract oxygen from every known compound.

§ 439. Our *qualitative* analysis of the classical elements has thus conducted us to such a preliminary acquaintance with the metallic elements as a class, and of the specific characters of the non-metallic elements, oxygen, nitrogen, hydrogen, and carbon, as will enable us now to proceed to the examination of their *quantitative* relations, and the illustration of the laws which limit the action of chemical affinity in composition and decomposition.

§ 440. It is curious to remark, that although air and water are not elementary forms of matter, according to the guess of the ancient Greek philosophers, the four simple substances of which they are composed form alone, by their different combinations, the structure of all the most important and familiar substances which minister to our necessities.

They constitute some of the most powerful acids and alkalies, and many of our most useful salts.—All the varieties of flame, and the means of artificial illumination,—all the forms of fuel, wood, coal, oil, &c.,—many of our most useful medicines, as well as some of the most deadly poisons,—all our articles of vegetable food,—flour, starch, sugar, wine, beer, &c., and of vegetable food,—jelly, meat, oils, fat, &c., are constructed solely of carbon, oxygen, hydrogen and nitrogen. They form the basis, in short, of the whole animal and vegetable creation, as well as of a vast variety of inorganic substances; and the atmosphere in which they are all included appears to be the grand storehouse of the raw materials from which all these wonderful and varied products are derived, and to which they all return.

§ 441. It may also be said that, on the other hand, the inorganic strata of our globe, or rather of that superficial shell with which alone we are acquainted, are all constituted of earthy materials,—they are all oxides, and bear the marks in many cases of products of combustion.

§ 442. It is, however, the chemistry of nature alone which can put these elements together in their more complicated forms; the products of animal and vegetable structure defy, as yet, the synthetic powers of our art. We can form many inorganic compounds, and we can often change one organic compound into another, but to build up a particle of sugar, or of wood, or a piece of flesh, simple as we can prove their composition to be by analysis, is beyond our power.

The examination to which we will now proceed of the laws of chemical composition and decomposition must be conducted with the strictest reference to quantity, determined both by weight and by measure.

LAWS OF COMPOSITION.

§ 443. The limits within which the action of chemical affinity is restricted are much narrower than those of the mere force of adhesion, and both the primary and secondary combination of bodies take place in a few *definite*, fixed, and unalterable proportions. We may form chemical mixtures of two or more bodies in the fluid state, in every conceivable proportion; and solutions may be effected, of solids and gases in liquids, in every proportion within the limits of saturation; but the compounds of any two chemical elements, or any two chemical compounds, are very few, and never vary in their specific proportions.

§ 444. To illustrate this by a familiar instance, let us take the primary combination of carbon and oxygen, and the secondary combination of this compound, or carbonic acid and lime. We have already described the combustion of this element in oxygen (§ 414); and if the experiment be conducted with a due regard to weight, we shall find that 27.2 parts of carbon, combined with 72.8 parts of oxygen-gas, to form 100 of carbonic acid, and this would be the same whether we burned charcoal or the diamond. If, on the other hand, we were to analyze 100 parts of carbonic acid we should find the same proportions of the elements, whether we extracted the compound from lime-stone, or obtained it from fermenting liquids, or by the process of respiration.

§ 445. Again: we can obtain the compound of carbonic acid and lime by the direct action of the acid and base, or from the rocky strata of the globe; from chalk, or secondary limestone, or primary marble: formations which, according to the speculations of geologists, may be separated from one another by intervals of time reckoned by myriads of ages. We can obtain it from coral, the work of marine zoophytes, fossilized by time or recently deposited, or from the secretions of a fowl of yesterday; and in every case,—various as must have been its origin,—we shall find that 100 parts contain precisely 44 parts of carbonic acid and 56 parts of lime.

§ 446. We may satisfy ourselves that the same law of *definite proportions* is maintained in the combination of oxygen and hydrogen, which constitutes water; and as the elements are in the gaseous state, they may be determined by measure as well as by weight (104). We have already seen that in the process which has been described for collecting the products of the detonation of these two gases, it is necessary that they be mixed very accurately, in the proportion of two of hydrogen to one of oxygen (§ 426). In these proportions they enter into combination, and in no other; and if either

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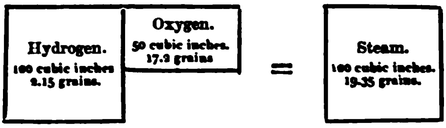
(104) The combinations of bodies in definite volumes are clearly represented by symbols of the following kind; in which a standard volume is represented by a square, and a half volume by a half square.



This indicates that a volume of hydrogen combines with half a volume of oxygen to form one volume of steam; and the weight of 100 cubic inches, thus derived from theory, agrees very nearly with that which we have previously adduced from experiment (§ 203).

gas were in excess, the surplus would be left after the detonation, and would very soon accumulate, and prevent fresh portions of the mixture entering the apparatus. As the specific gravity of each gas is fixed, these proportions by weight are equivalent to 1.1 parts of hydrogen and 88.9 parts of oxygen per 100.0.

§ 447. It is not that the previous mixing of the gases in these proportions has any influence upon the result; for let the mixture be made in any proportions, the combination will take place in but one. The proportion of either may be so great with regard to the other, that detonation will not take place; thus, 1 measure of hydrogen may be mixed with 100 of oxygen, and no general combustion will ensue upon the passage of an electric spark; but upon continuing the electric discharge through the mixture, combination will slowly proceed by the action of each successive spark, exactly in the same definite proportions as if it had resulted at once. In this slow process combustion takes place in that portion of the gas immediately subject to the action of the sparks; but the temperature of the surrounding gas is not sufficiently raised thereby to enable the combustion to spread beyond their immediate influence. The accurate analysis of water from any source, purified from all foreign admixture, by whatever agent effected, will give the same quantitative result. Oxygen and hydrogen gases, also, unite slowly in the same proportions, when they are exposed to a temperature above the boiling-point of mercury, and below that at which glass begins to appear luminous in the dark.

§ 448. But though the composition of substances is thus definite and limited, it by no means follows that bodies can combine only in one proportion: on the contrary, most bodies can unite in several; but all the compounds are equally definite and fixed. They are, moreover, restricted by this singular law, namely, that the combining quantities always bear some simple ratio, to each other. Thus, when two gases combine together, in equal volumes, to constitute a definite compound, if more combinations take place, they will be in the proportion of 1 volume to 2, or 1 to 3, or 1 to 4, &c., or the compounds may form a series, in which the ratios may be as 2 to 3, or 2 to 5, &c. The proportions are always some simple multiples or sub-multiples of each other. Such variations of proportions admit of nothing intermediate, and they as completely constitute new species of matter as do the combinations of different elements. We will endeavour to illustrate the laws of definite and multiple proportions by the combinations of nitrogen with oxygen.

§ 449. The chemical affinity between these two elements is very powerful; but nevertheless it is extremely difficult to cause them to unite directly. This is doubtless one provident security for the permanence and salubrity of the mixed atmosphere which we breathe; for all their compounds are noxious, and most of them corrosive and poisonous.

The slow combination of nitrogen and oxygen may be laboriously effected in the same way as that of hydrogen and oxygen when not in explosive proportions; that is to say, by passing a succession of electric sparks through the mixture (§ 447); but in no proportions of the two gases is sufficient heat disengaged to maintain the combustion by itself. We owe to Mr. Cavendish the discovery that the formation of one of the most powerful acids with which we are acquainted, namely, *aqua-fortis*, or *nitric acid*, is the result of this process.

By arranging two metallic wires upon a piece of damp litmus paper, in such a way that a rapid succession of sparks may pass from the prime conductor of the electrical machine between them, we may always obtain evidence of this action in the red line which will appear in their path; and if a piece of filtering paper be steeped in a solution of potassa, and the sparks be passed over it in the same way, the acid as it is formed will neutralize the alkali, and the paper will afterwards burn with scintillations, just as if it had been steeped in solution of nitre.

§ 450. Nitre, which is spontaneously produced upon the soil in many parts of the world, as Spain and the East Indies, and is an article of extensive commerce, is, in fact, a secondary compound of this acid and alkali. It is the great source of all the nitric acid which is used in the arts, which is procured from it by the superior affinity of sulphuric acid, or oil of vitriol, for the potassa with which it is combined. The salt is put into a retort, the acid poured upon it, and a gentle heat applied; the nitric acid passes over in the state of vapour, and is condensed in a proper receiver (105).

In this compound, nitrogen is oxidated to the utmost; but before we state the definite proportions of its two elements, it will be more satisfactory to examine the compounds which may be obtained by the partial abstraction of oxygen from it.

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(105) The process may be conducted in the apparatus represented in the next page. *a* is a tubulated retort, connected with the receiver, *b*, the tube of which descends into the bottle, *c*. When the retort is

§ 451. Upon putting some metallic zinc into a mixture of nitric acid and water, in the proportion of 1 measure of strong acid to 16 measures of water, and applying a moderate heat, a gentle effervescence will take place, and a gaseous product may be collected. In this operation the zinc takes oxygen from a part of the nitric acid, and forms the same oxide which is produced by its combustion in oxygen, and this combines with another portion of the acid. But the decomposition is not complete, and we shall find that the gas which passes over is not nitrogen, but a compound of nitrogen with the smallest proportion of oxygen, and possessed of far different properties.

§ 452. This new combination of nitrogen and oxygen may be best obtained, however, and in the purest state, by the action of heat upon a salt which we shall hereafter particularly examine, and which used to be called *nitrum flammans*, but is now known by the name of *nitrate of ammonia*. Some of this compound may be placed in a glass retort, and gently fused over an argand lamp. It must be cautiously kept simmering, when it will give off the gas in question, which may be best collected in bottles over hot water, as it is considerably soluble in that liquid when cold.

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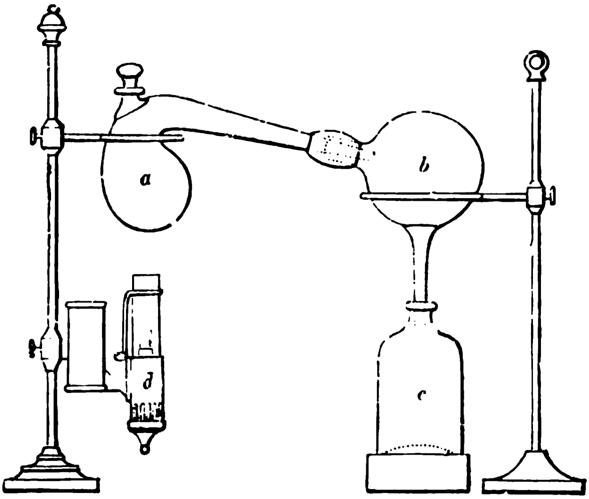
charged with the proper proportions of nitre and oil of vitriol, and a gentle heat applied by means of the lamp, *d*; the nitric acid passes over in vapour, and is condensed in the receiver, *b*, from whence it flows into the bottle, *c*.



It is a colourless elastic fluid, considerably heavier than common air, 100 cubic inches weighing about 47.3 grains. It is not, however, permanently elastic; for by subjecting it to a pressure of about 50 atmospheres, Dr. Faraday obtained it in the liquid form at 45° Fahrenheit. It was thus procured by sealing up some nitrate of ammonia in a bent tube, and heating it at one end, while the other end was kept cool; an experiment which must always be attended with risk from the enormous pressure upon the tube. It has a sweetish taste and faint agreeable smell, both of which it imparts to water; which, at ordinary temperatures, absorbs about its own bulk of the gas. Animals when wholly confined in it, speedily die; but it may be breathed a short time with impunity, from its becoming diluted with the atmospheric air in the lungs.

It produces a most extraordinary excitement in the persons who inhale it. The experiment may be tried by filling a clean bladder or silk bag with the pure gas, and inhaling it frequently through a pipe attached to a stop-cock. The sensations which it produces have been variously described by different persons; but most of them have agreed that they are very agreeable, and much resemble the exhilarating effects of spirituous liquors. It has generally occasioned an irresistible propensity to laughter and muscular exertion; not followed by that depression and sense of lassitude which generally succeed excitement from fermented liquor.

It has no action upon vegetable colours, and is therefore neither acid nor alkaline. Many substances, when introduced into it in a state of inflammation, continue to burn, and with increased splendour, from their superior affinity for the oxygen with which they combine, setting the nitrogen free. The glowing wick of a partially extinguished taper is immediately kindled into flame. Iron wire and red hot charcoal burn in it with nearly the same splendour as in oxygen gas, but for a shorter time; and the action of phosphorus is so violent as almost to amount to explosion. When mixed with hydrogen, it will detonate by the application of flame, or by an electric spark.

§ 453. Its exact analysis may therefore be thus performed:—Mix a measure of the gas with an equal measure of hydrogen, and fire the mixture in the apparatus before described (§ 431). One measure of pure nitrogen will remain. The measure of hydrogen has wholly disappeared, and must have entered into combination with half a measure of oxygen; for these are the proportions in which we have previously ascertained these two elements to combine. We further conclude that, when in combination with the nitrogen, the whole volume of the latter, and the half volume of the former, must have been condensed into one volume; and a comparison of the specific gravities of the gases confirms this conclusion: for 100 cubic inches of nitrogen, weighing 30.1 grains, uniting with 50 cubic inches of oxygen, weighing 17.2 grains, without altering its bulk, must form a compound, 100 cubic inches of which will weigh 47.3, as has been found from direct experiment (106).

§ 454. And this leads us to remark further upon the law of definite and multiple proportions in relation to gases, that, whenever, in composition or decomposition a change of volume takes place, the enlargement or condensation always bears some simple ratio to the original bulk. It is always double or triple, or half, &c. Thus, in the combination of two volumes of hydrogen with one of oxygen, the three volumes are condensed into two of steam. 100 cubic inches of hydrogen weighing 2.15 grains, added to 50 cubic inches of oxygen 17.2, are equal to 19.35 grains, the weight of 100 cubic inches of steam; as it is found by experiment when properly corrected for temperature and pressure (104).

This compound of nitrogen and oxygen was discovered by Dr. Priestley; who, according to the favourite hypothesis of the day, named it dephlogisticated nitrous air.

§ 455. The deoxydation of nitric acid may be effected in a less degree by mixing it with only one half its bulk of water, instead of diluting it with sixteen times its bulk. The action of the zinc upon it is much more violent: but for the purpose of collecting the product it is best to employ mercury. Upon pouring the acid upon the metal, a violent effervescence soon ensues, which, at first,

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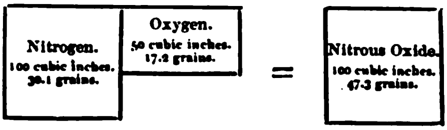
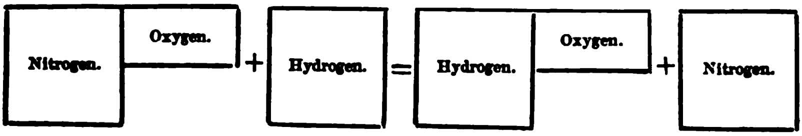
(106) The following will be the symbolic representation of this compound of nitrogen and oxygen by volume.



And with regard to its decomposition by hydrogen,—



produces a red vapour in the retort; but upon collecting the gas, it is found to be colourless.

This gas is a permanent elastic fluid; very sparingly soluble in water, and does not, when pure, act upon vegetable colours. It is wholly irrespirable. The flame of most combustible bodies, as of a taper or sulphur, is instantly extinguished by being immersed in it, but it parts with its oxygen to charcoal, or phosphorus, if introduced in a state of strong ignition; and they burn in it with increased energy. It does not explode when mixed with hydrogen in any proportion; but it colours its flame green when mixed with it and burnt in the common air.

It is but little heavier than common air, 100 cubic inches weighing about 32.2 grains; when mixed with oxygen or common air, deep red fumes are generated, and if the experiment be made over water a great absorption takes place; and when the oxygen is perfectly pure, and the mixture made in proper proportions, they combine together and totally disappear. The composition of this gas has been accurately ascertained by the careful combustion of charcoal in a known measure of it. After the operation, an equal measure of gas remained, which was found to consist of half a measure of carbonic acid, which was absorbed by potassa, and half a measure of nitrogen.

Now, charcoal combines with oxygen to form carbonic acid without altering its bulk, and hence, we conclude that the nitrogen of the compound was combined with an equal volume of oxygen without change of volume, a result which exactly agrees with its specific gravity; for 50 cubic inches of nitrogen, 15 grains, added to 50 cubic inches of oxygen, 17.2 grains, make a sum of 32.2 grains, the weight as we have already stated of 100 cubic inches of the gas (107).

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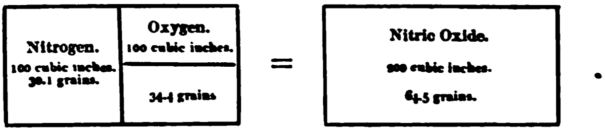
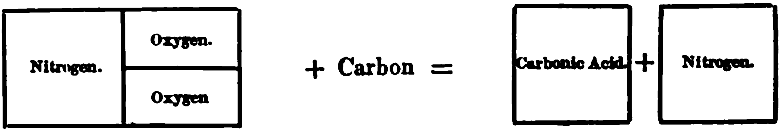
(107) The constitution of the second compound of nitrogen and oxygen may be represented as follows:—



No condensation of volume here takes place.

Its decomposition by charcoal may be thus represented.



Here we find, then, that the quantity of oxygen combined with the nitrogen, is exactly double that of the preceding compound.

§ 456. The difference of the action of hydrogen upon the two oxides of nitrogen is remarkable, and is probably referrible to the state of condensation in the elements of the first. The divellent affinity of the hydrogen for the oxygen, is here assisted by the elastic force with which it tends to escape from coercion. In the latter, no compression of the elements exists, and no such auxiliary force is exhibited.

§ 457. Before we proceed with our investigation, we must say a few words upon the mode of naming these new creations of chemistry;—these unfamiliar forms of matter, to the number of which the progress of science is daily adding;—for which common language cannot have provided distinctive appellations. Unless this be done upon some well-digested plan, utter confusion arises; and without some artificial helps, the most retentive memory would be insufficient to the task of recalling them at need.

We are indebted to the labours of four eminent French chemists,—Lavoisier, Berthollet, Guyton Morveau, and Fourcroy,—for having effected this important service; their systematic nomenclature has, indeed, greatly conduced by its simplicity, and its ready adaptation to new facts, to the advancement of science. The principles of this nomenclature, which have required some modification and extension with the progress of experience, we shall endeavour to explain as we proceed, and to apply as occasion may require; in conformity with our plan of proceeding gradually from the known to the unknown.

§ 458. Trivial names, or names which are not descriptive, may be given to simple substances; and they are even the best when others may be readily compounded from them; but it is of great importance that compound bodies should be designated by names which may recall their constitution. Of all elementary substances, oxygen has the greatest range of affinity; and it is capable of entering into combination with all the other elements in a vast variety of proportions; it is therefore of great importance to distinguish its compounds clearly. Of its primary products, those which are not acid are termed *Oxides:* thus, in the systematic language, water is an oxide of hydrogen, and the two compounds of oxygen and nitrogen which we have just examined, are oxides of nitrogen. When more than one such compound with the same body is known, they are distinguished as first, second, and third oxide, &c., by the appellations, derived from the Greek ordinals, of *proto*xide, *deuto*xide, *trito*xide, &c., or the furthest degree of oxidation which does not confer the property of acidity, is distinguished by the Latin particle *per*, indicating the superlative degree; *per*oxide of mercury designating the red compound, to which we have so often referred, of that metal with oxygen.

§ 459. Having found that the law of multiple proportions is maintained, both by measure and weight, in the composition of the protoxide and deutoxide of nitrogen, let us proceed to examine the next combination of these elements; and this may be produced synthetically by the addition of oxygen to the deutoxide. The gases for this purpose must not be mixed over water or mercury; but in an exhausted glass globe or receiver. In this way, if one measure of oxygen be added to two measures of the deutoxide, they will be condensed into one-third of their joint volume, and form a deep orange-coloured gas, which is the *nitrous acid*. Now a volume of the deutoxide, we know, consists of half a volume of nitrogen, and an equal measure of oxygen: two volumes, therefore, contain one volume of nitrogen and one of oxygen, and another volume of oxygen added, condenses the whole three volumes into one volume of the new compound, which must, therefore, contain twice the oxygen of the deutoxide, and four times the oxygen of the protoxide (108).

§ 460. This gas will support the combustion of common combustibles; an inflamed taper and phosphorus burn in it most vividly, and charcoal with a dull red light. Water dissolves it with great rapidity, and acquires a green tint, which changes to blue, and finally to yellow, as more of the gas is absorbed. The solution is intensely sour, reddens the blue colour of litmus, and stains animal substances yellow.

§ 461. When a ray of light, which has been passed through even a very dilute mixture of this gas and common air, is exa-

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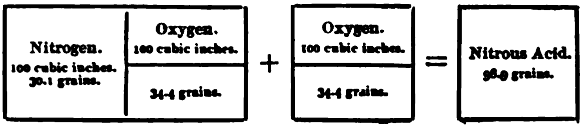
(108) The composition of this compound of nitrogen and oxygen, and its synthesis, from the deutoxide and oxygen, may be thus represented:—



mined with a prism, the spectrum is found crossed with a series of black lines of a similar character to those to which we have before alluded, as being perceptible in a well defined solar spectrum (§ 233). Heat has a curious influence upon its action upon light; at a low temperature or 0° Fahrenheit, it is colourless; at 32°, it is of a yellow colour; and at common atmospheric temperatures, it assumes various shades of orange yellow. As it becomes hotter, its colour deepens till a ray of the brightest sunshine is incapable of penetrating through even a dilute mixture.

The gas is very easily condensed by a temperature of 0° to the liquid state. In this form it is powerfully corrosive; possesses an intense acid taste and pungent odour, boils at 82° and rapidly evaporates at lower temperatures.

§ 462. By passing deutoxide of nitrogen slowly into oxygen gas standing over water, we form the nitric acid with which we set out. In this operation, four volumes of the former gas unite with three volumes of the latter, and the compound must therefore consist of two volumes of nitrogen and five volumes of oxygen. The acid, as it is formed, is absorbed by the water, and would indeed appear to be incapable of existing except in union with that liquid, or some saline base. The strongest acid which can be procured by the process of distillation from nitre has a specific gravity of 1.504, in which three proportions of the dry acid, constituted as above stated, are condensed with two volumes of steam (109).

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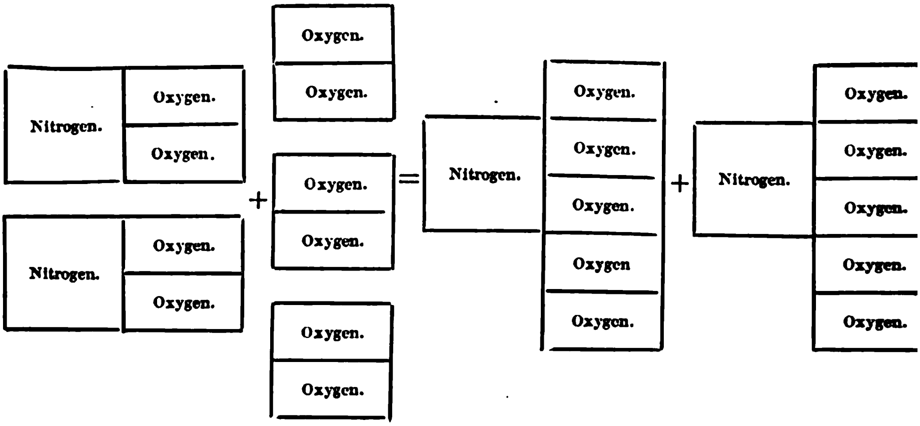
(109) The composition of the nitric acid, and the changes which take place upon slowly passing deutoxide of nitrogen into oxygen, is here exhibited in volumes of the ingredients:—



§ 463. The *aqueo-nitric* acid is a highly corrosive fluid, and acts as a powerful cautery when applied to the skin, which it stains of a permanent yellow. It is often decomposed with great violence by substances which have a strong affinity for oxygen; which enters so largely into its composition. If it be brought into contact with hydrogen at a high temperature, a violent detonation will be the consequence; but the experiment is dangerous, and should not be made without great caution. When poured upon warm dry charcoal in powder, combustion ensues, with the emission of copious fumes arising from the disengagement of deutoxide of nitrogen. Oil of turpentine may be inflamed by suddenly pouring strong nitric acid into it.

Chemists continually employ this acid for the purpose of bringing bodies to their maximum state of oxydation. Nearly all the metals may be thus converted into oxides, and all vegetable and animal substances may be combined with oxygen. The acid, during these processes, yields up three-fifths of its oxygen, and passes to the state of deutoxide of nitrogen: an example of which decomposition we have in the process for making that gas.

§ 464. When more than one acid is formed by the combination of any body with oxygen, the chemical nomenclature distinguishes them by the terminations *ous* and *ic*, conferring the first upon the acid which contains the least oxygen, and the second upon that which contains the most. We denominate the compound of one volume of nitrogen and four of oxygen, the nitr*ous* acid, and that of one and five the nitr*ic*.

§ 465. Thus, then, we have become acquainted with four compounds of nitrogen and oxygen, in which the proportions of the latter element to the former, taken by measure, are in the higher compounds multiples of the lowest: distinguishing them by the initial letters:—

1 N + ½ O = Protoxide of nitrogen.
1 N + 1 O = Deutoxide of nitrogen.
1 N + 2 O = Nitrous acid.
1 N + 2½ O = Nitric acid.

Here it will be observed that to form a complete series, there is wanting a compound between the deutoxide and nitrous acid of 1 N + 1½ O, which for a long time was unknown; but for which M. Gay Lussac, who first obtained it, was induced to seek carefully by experiment, in full reliance upon the invariableness of the law which we are endeavouring to illustrate.

§ 466. By forming a mixture of deutoxide of nitrogen and oxygen over mercury, instead of water, in the proportion of four volumes of the former and one of the latter, and throwing in a little solution of potassa, a combination takes place, and an acid is formed which immediately enters into secondary combination with the alkali; but which cannot afterwards be separated without undergoing decomposition. The compound is of so unstable a nature that whenever a stronger acid is added for the purpose of disengaging it from the base, it is resolved into the two more permanent compounds, deutoxide of nitrogen and nitrous acid. It is of very little importance except as supplying the link which was deficient in our chain of simple multiples. This acid was distinguished by its discoverer, by prefixing the Greek preposition *hypo*, signifying under, to the nitrous acid, and thus indicating its inferior degree of oxygenation; he called it the *hypo-nitrous acid* (110).

§ 467. The quantities thus expressed by measure, are easily converted into the corresponding quantities by weight; when the same law of multiple proportions will of course appear; as in the following Table:—

100 O + 177 N = Protoxide of nitrogen.
200 O + 177 N = Deutoxide of nitrogen.
300 O + 177 N = Hypo-nitrous acid.
400 O + 177 N = Nitrous acid.
500 O + 177 N = Nitric acid.

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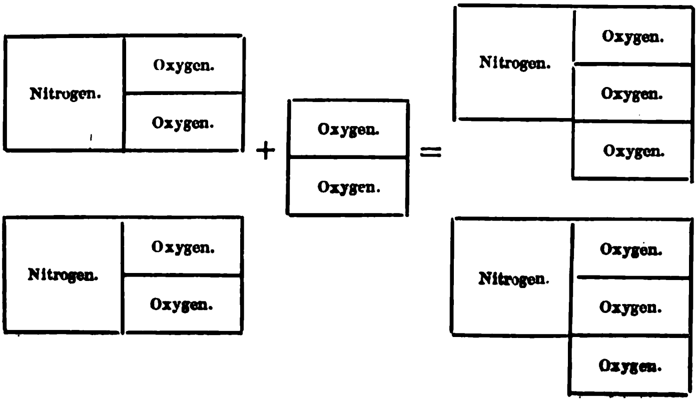
(110) The composition of the hypo-nitrous acid, by volume, is as follows:—



Between these compounds there is none intermediate, and the constitution of each is invariably fixed and definite.

§ 468. The complete change of properties which characterizes these definite combinations under the force of affinity, cannot, perhaps, be better exemplified than by this series of compounds: each is essentially different from the other, and as regards their effects upon the human constitution, pleasure and suffering, laughter and death are at the two extremes. In reviewing them all, it is almost impossible not to be impressed with the wonderful nature of that species of attraction, which by the approximation of the particles of two bodies, and the mere variation of the proportions, can confer such essentially different qualities upon matter! In the atmosphere by which we are surrounded, we are presented with an active principle, essential to the existence of life, but injurious in its pure state, diluted by measure and weight with an inert fluid to the exact proportion which is most beneficial to animal existence: it is perpetually consumed, and perpetually renewed; but never falls short of its determined quantity. This bland, tasteless, inodorous, invisible mixture, in which we are constantly immersed, and upon the maintenance of which our existence depends, is, by the approximation of its particles in a manner to us mysterious, capable of being converted into a poisonous, corrosive, suffocating red vapour, which instantly destroys all organized matter. By approximating them in other proportions, an intoxicating deleterious air is produced, or compounds with other properties, but all destructive of life. Such affinities, it is clear, exist; but, providentially, are controlled by the same power which ordained the laws of nature.

§ 469. The course of our investigation will lead us next to inquire whether nitrogen be capable of forming any combinations with hydrogen, and what the nature of these combinations may be.

The two gases may, of course, be mixed together in any proportions; but there are no known means of causing them to unite directly in a more intimate manner. One such compound may, however, be formed indirectly. Strong nitric acid will not be acted upon by tin; and indeed there are several metals, iron amongst the number, which remain perfectly bright in acid of the specific gravity 1.5. When diluted with half its bulk of water, rapid decomposition of the acid takes place, and tin is converted into a white oxide, with a violent extrication of deutoxide of nitrogen. If some of the bulky white powder thus produced be rubbed in a mortar with some alkaline base, such as potassa or lime, the well-known pungent smell of *hartshorn* is emitted; and a piece of moistened turmeric-paper held in the fumes will be turned brown, testifying the escape of some volatile substance with alkaline properties.

In this process the tin not only effects the decomposition of the acid, but also of the water, combining with the oxygen of both, and a portion of nitrogen and hydrogen are set free at the same time, and immediately form a new compound. This compound is alkaline, and, consequently, enters into secondary combination with a portion of the acid. By washing the oxide of tin, and evaporation of the solution, the resulting salt may be obtained in crystals.

§ 470. There is a saline body of the same nature well known in the arts by the name of *sal-ammoniac*, which was so called because it was formerly obtained near the ruins of the temple of Jupiter Ammon, in Africa; if some of this salt, finely powdered and mixed with an equal quantity of unslaked quick-lime in powder, be introduced into a small glass retort, and exposed to heat, it will give off a gas which may be collected over mercury, but is rapidly absorbed by water. It possesses the peculiar pungent smell to which we have just referred, and when drawn into the mouth destroys the cuticle; and an animal plunged into it is instantly suffocated.

It is colourless, and possesses all the mechanical properties of the air. It possesses an acrid, caustic, taste, which it communicates to its watery solution. The flame of a taper plunged suddenly into it is extinguished, but if slowly and cautiously introduced the flame becomes enlarged with a kind of yellow halo, indicating a disposition of the gas itself to burn. In fact, if a small jet of it be thrown into a jar of oxygen, it may be ignited: the product of the combustion being water and nitrogen.

§ 471. A mixture of the gas with oxygen, in the proportion of two volumes to one and a half, may be inflamed just as a mixture of hydrogen and oxygen.

The mere passing of electric sparks through it effects its decomposition; and it may also be decomposed by transmitting it over red-hot iron, or copper placed in a tube (111). By these processes its bulk is gradually enlarged; and when two or three hundred discharges have passed through a cubic inch of it, it will be found to have doubled its volume. Two volumes, therefore, by their decomposition, produce four volumes, which are found to consist of three volumes of hydrogen and one volume of nitrogen.

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(111) The gas for this purpose may be contained in a bladder, *a*, from which it may be gradually expelled through the tube, *b b*, which contains a coil of copper wire, and is kept heated in the furnace, *c*. The

§ 472. Now, 150 cubic inches of hydrogen weigh 3.22 grains, and 50 cubic inches of nitrogen 15.07 grains, making together 18.29 grains; which, as two volumes are exactly condensed into one, will be the calculated weight of 100 cubic inches of this compound, and agrees with the result of direct experiment (112). It has been named *ammonia*, from the sal-ammoniac from which it was first procured.

§ 473. Ammonia has been liquefied by Dr. Faraday with a pressure of 6½ atmospheres at 50° Fahrenheit. Its solution in water is an article of great importance and extensive use. It may be prepared by passing the gas, as it is formed at once, into water; which, at the temperature of 50°, will take up 670 times its own volume. The bulk of the water is thereby increased, and its specific gravity

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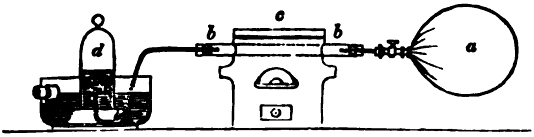
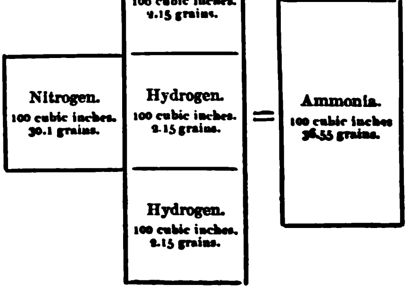
gases arising from the decomposition may be collected in the jar, *d*, standing in the water-trough and measured.



(112) The results of this analysis are thus represented in volume. The condensation is of four volumes into two:—



diminished: that of a saturated solution being .875. The solution may be more conveniently made by covering the mixture of lime and sal-ammoniac with water, and after allowing it to stand for some hours, pouring off the clear solution and distilling. The force of adhesion between the ammonia and the water is so great, that the solution rises in vapour, and is afterwards condensed. The solution possesses the peculiar pungent smell, taste, and alkaline properties of the gas itself, and has the same action upon vegetable colours.

§ 474. The affinity which we have been hitherto considering has been between the ultimate particles of bodies: the chemical composition, which hence results, by no means in every case saturates or satisfies their chemical attraction, but leaves many of the compounds with the power of entering into *secondary combination*, as *proximate principles*, from which new classes of bodies arise with perfectly new properties, but in which the power of combination is satisfied, and the chemical forces are in a state of equilibrium. These secondary combinations again are strictly subject to the same laws of definite and multiple proportions. We will illustrate this more particularly by the mutual reaction of ammonia and the nitric and carbonic acids, which we have formed out of the ingredients of the atmosphere.

§ 475. By carefully dropping a solution of ammonia into dilute nitric acid they may be made exactly to neutralize one another, and the exact point of mutual saturation may be easily ascertained by colouring the first green and the second red by some blue vegetable colour. The blue colour will be restored when the acid and alkaline properties disappear. The solution will then be neither acid, corrosive, alkaline, nor caustic, but its taste will be saline and cooling. By careful evaporation of the water at a temperature not exceeding 100° Fahrenheit, a salt may be obtained in crystals, which is the same as that which we described as formed by the violent reaction of water, nitric acid, and tin (§ 469). These crystals have been ascertained to be composed per cent. of:—

Acid	67.63
Alkali	21.14
Water	11.23
	100.00

We may separate the whole of its acid from this compound, by the stronger affinity of sulphuric acid for the ammonia: or we may separate its alkali by the superior attraction of lime for the nitric acid.

It is also the same salt as that which we employed for the formation of the protoxide of nitrogen (§ 452): and if this experiment be carefully conducted, it will be found that its full weight will be obtained in protoxide and water. It is clear, then, that the whole influence of the heat is to produce a new and more stable arrangement of the heterogeneous particles concerned without any loss: and the study of this play of affinities we shall find very instructive.

§ 476. That the water should pass off at a high temperature, any one might probably anticipate; but that the hydrogen of the ammonia should be exactly sufficient to combine with the oxygen of the acid, and leave the nitrogen of both in the lowest degree of oxygenation, as the protoxide, is very remarkable. There is not the slightest excess or deficiency in any of the elements; but the definite proportions of the first compounds contain the exact quantities for the second, which are equally definite. Let us state the proportions of each per cent., as we have just done the proportions of the proximate principle of the salt.

NITRIC ACID	Nitrogen	25.9
	Oxygen	74.1
		100.0
AMMONIA	Nitrogen	81.13
	Hydrogen	18.87
		100.00
PROTOXIDE OF NITROGEN	Nitrogen	63.6
	Oxygen	36.4
		100.0
WATER	Hydrogen	11.1
	Oxygen	88.9
		100.0

§ 477. Now, under this form of stating the proportions in which bodies are combined, in 100 parts of the compound, which would obviously be the first mode of comparing the results of analyses, a great and comprehensive truth for a long time lay hid, the evolution of which constitutes one of the greatest steps that the science ever made. It will at once appear by changing the expressions of all into the same ratios with reference to one common standard of comparison. Let us, for instance, assume a fixed measure of 100 cubic inches of nitrogen for this purpose; then, according to our preceding results,—

$$\begin{array}{l}\left.\begin{array}{l}100\ N + 250\ O = \text{Nitric acid.}\\ 100\ N + 300\ H = \text{Ammonia.}\\ 100\ H + 50\ O = \text{Water.}\end{array}\right\}\text{Nitrate of Ammonia.}\\ \hline 200\ N + 400\ H + 300\ O \\ \hline \hline\end{array}$$

But these proportions of the elementary substances are capable of being arranged in the following order:—

$$\begin{array}{l}100\ N + 50\ O = \text{Protoxide of Nitrogen.}\\ 100\ N + 50\ O = \text{Protoxide of Nitrogen.}\\ 100\ H + 50\ O = \text{Water.}\\ 100\ H + 50\ O = \text{Water.}\\ 100\ H + 50\ O = \text{Water.}\\ 100\ H + 50\ O = \text{Water.}\\ \hline 200\ N + 400\ H + 300\ O\ \ (113).\\ \hline \hline\end{array}$$

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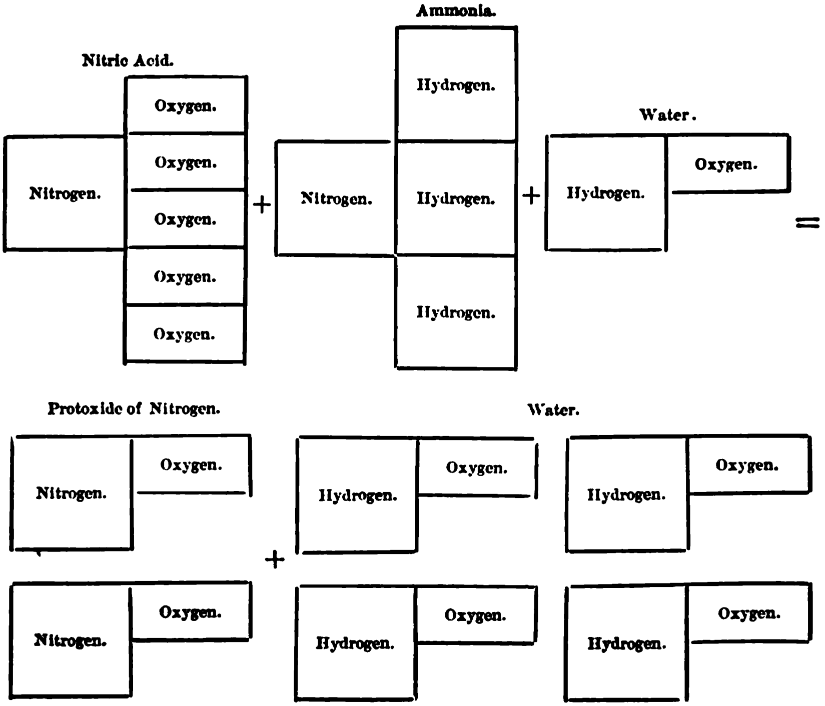
(113) The symbolic representation of this change is as follows:—



§ 478. Or, let us make the same comparison by weight, with reference to 100 grains of oxygen as a standard.

$$\left.\begin{array}{rl} 177\ \mathrm{N} + 500\ \mathrm{O} = & \text{Nitric acid.} \\ 177\ \mathrm{N} + 37.5\ \mathrm{H} = & \text{Ammonia.} \\ 12.5\ \mathrm{H} + 100\ \mathrm{O} = & \text{Water.} \end{array}\right\}\text{Nitrate of Ammonia.}$$

$$\underline{\underline{354\ \mathrm{N} + 50\ \mathrm{H} + 600\ \mathrm{O}}}$$

which are equivalent to:—

$$\begin{array}{rl} 177\ \mathrm{N} + 100\ \mathrm{O} = & \text{Protoxide of nitrogen.} \\ 177\ \mathrm{N} + 100\ \mathrm{O} = & \text{Protoxide of nitrogen.} \\ 12.5\ \mathrm{H} + 100\ \mathrm{O} = & \text{Water.} \\ 12.5\ \mathrm{H} + 100\ \mathrm{O} = & \text{Water.} \\ 12.5\ \mathrm{H} + 100\ \mathrm{O} = & \text{Water.} \\ 12.5\ \mathrm{H} + 100\ \mathrm{O} = & \text{Water.} \\ \hline \underline{\underline{354\ \mathrm{N} + 50\ \mathrm{H} + 600\ \mathrm{O}}} & \end{array}$$

Here it is evident that a definite proportion of the crystallized salt, formed by nitric acid, ammonia, and water, is exactly equivalent to two proportions of the protoxide of nitrogen and four proportions of water.

§ 479. The ratios of the combining substances, though differently expressed, are the same as those stated in 100 parts of each compound; but we now perceive that there is a much more extensive connexion between them, and that they are all definitely related. Thus, 177 parts of nitrogen combine with 100 parts of oxygen to constitute the protoxide of nitrogen, and the same quantity combines with 37.5 parts of hydrogen to form ammonia; and this is exactly three times the amount of that element which combines with 100 of oxygen to form water. Again, if we add together on one hand the proportions of nitrogen and oxygen which enter into the composition of nitric acid, and on the other the proportions of nitrogen and hydrogen which form ammonia, the respective sums will express the ratio in which the acid and alkali combine: thus,—

$$\begin{array}{rll} 177\ \mathrm{N} + 500\ \mathrm{O} = & 677 & \text{Nitric acid.} \\ 177\ \mathrm{N} + 37.5\ \mathrm{H} = & \underline{214.5} & \text{Ammonia.} \\ & \underline{\underline{891.5}} & \text{Nitrate of ammonia.} \end{array}$$

And if we take the proportions of oxygen and hydrogen in water, we shall have the amount of that compound which enters into the constitution of the crystallized salt: thus,—

$$\begin{array}{r l} 100\ O + 12.5\ H = 112.5 & = \text{Water.} \\ 891.5 & = \text{Nitrate of ammonia.} \\ \hline 1004.0 & = \left\{\begin{array}{l}\text{Crystallized nitrate of} \\ \quad\text{ammonia.}\end{array}\right. \end{array}$$

§ 480. A similar relation exists between all the compounds which result from the action of chemical affinity; and certain definite unchangeable quantities of the elementary substances are *equivalent* to each other in combining, either in single or multiple proportions: while the amounts of the several proximate principles, so constituted, are also *equivalent* to one another in entering into secondary combination.

§ 481. The full development of the laws of *definite*, *multiple*, and *equivalent* proportions in chemical combination, can only be found in the complete body of chemical science; but it may contribute to that *clear idea* of their nature and scope which it is desirable to obtain at the outset to illustrate them by the mutual exchange of principles which may take place between two salts by double decomposition, and which may be effected without going beyond those forms of matter with which the course of our inquiry has already made us acquainted.

We have ascertained the composition of carbonic acid, both by analysis and synthesis, to be per cent. 72.73 oxygen and 27.27 carbon. With reference to 100 oxygen, the carbon would be 37.5; 137.5 therefore, or some simple multiple of this amount of carbonic acid, ought to be equivalent to 677. of nitric acid in combining with 214.5 of ammonia.

Upon making the experiment we shall find that, when one volume of carbonic acid and two volumes of ammonia are mixed in a glass vessel over mercury, a complete condensation ensues, and a saline body is produced in the form of a white powder. It therefore contains, in 100 parts by weight, 56 carbonic acid and 44 ammonia; or, with reference to 100 oxygen, 275. carbonic acid and 214.5 ammonia: 275. therefore (or, 137.5×2) is the quantity of carbonic acid equivalent to 677. nitric acid. Again, if we take 100.3 parts of the salt of nitric acid and ammonia, (composed of N A 67.7 + A 21.4 + W 11.2,) and decompose it by the superior affinity of lime, the whole of the ammonia will be driven off and replaced by 35.5 parts of that base, which are therefore equivalent to 21.4 of ammonia; and the salt remaining will consist of 67.7 nitric acid and 35.5 of lime.

§ 482. And now we have it in our power to apply the most convincing test of the accuracy of the law; for if we take equivalent solutions of the two salts, one formed of carbonic acid and ammonia, and the other of nitric acid and lime, and mix them together, a double exchange of acids and bases will take place: the carbonic acid will separate from the ammonia and combine with the lime (and the compound carbonate of lime being insoluble will be thrown down in the solid state): at the same time the nitric acid separating from the lime will combine with the ammonia (and will remain in solution). The exchange will be perfect, neither acid nor base of any kind will be in excess; but the quantity of lime which exactly sufficed to neutralize the nitric acid will be exactly sufficient to neutralize the carbonic acid; and the quantity of ammonia which was combined with the carbonic acid will be precisely that which is required to enter into composition with the nitric acid. The definite proportions of the ingredients of each compound are, in short, *equivalent* to each other in all other compounds into which they are capable of entering (114).

§ 483. As the decomposition of a compound by the stronger attraction of some other body for one of its components is said to take place by elective affinity, so this process of double decomposition and recomposition is designated *double-elective affinity;* and it sometimes happens that bodies which cannot be separated by the

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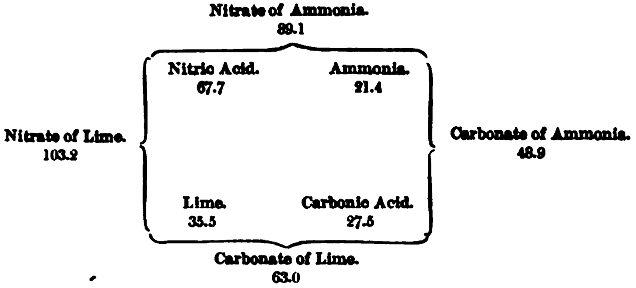
(114) The relations of the several equivalents which enter into the composition of the original and resulting compounds, are clearly seen in this diagram.



On the outside of the perpendicular lines are placed the equivalent quantities of the original compounds: the equivalent quantities of their proximate principles are placed within the same lines. On the outside of the horizontal lines are placed the new results, which are made up of a double exchange of principles; the equivalent proportions remaining the same.

single divellent force of the first, will yield to the combined action of the second.

§ 484. The laws of definite, multiple, and equivalent proportions in compositions and decompositions resulting from the force of affinity, constitute the foundation of chemical science. Their establishment has rendered mathematical precision attainable in all its reasonings and results, and facilitated its study and extension. The results of the crucible and the balance may thus be checked and corrected by calculations founded upon general principles; while every new fact at once finds a place in the general system, and is brought into association and comparison with previously known phenomena in a way the most advantageous to its examination. Every species of inorganic matter, whether elementary or compound, and many of organic composition, are now included in tables of equivalents, whose precision is such, that they are capable of being transferred to logometric scales; by the sliding rule of which the expression of their ratios may be changed and calculations facilitated, as by other sliding rules.

§ 485. For the unit of the scale, or standard of comparison, any substance might be adopted, provided its combining relations with a sufficient number of other bodies were accurately ascertained; but uniformity of practice is as much to be desired in this case as in those of the thermometer and barometer. Unfortunately, however, the cultivators of science have here, again, sacrificed a great general convenience to minor and speculative points, and two series of numbers are now in use to represent chemical equivalents; oxygen standing at the head of one, and hydrogen of the other. We have already given an example of the first, in the comparison which we have made of the combining proportions of such substances as we have had occasion to refer to with 100 parts of oxygen (§ 478). Whether oxygen be taken as 1, 10, or 100, makes no difference, except as regards fractions and the decimal point. The great practical objection to the scale is, the inconvenience of the high numbers, or the perpetual and necessary recurrence of fractions. One of the great advantages which a scale of equivalents offers, is its assistance to the memory, and this is greatly impaired by the complexity of fractional numbers.

§ 486. By assuming hydrogen = 1, or unity, we obviate this objection. Of all species of matter it enters into combination in the smallest proportion by weight, and an hypothesis has been formed, which yet requires confirmation, that the numbers representing other bodies are all simple multiples of its equivalent. However this may be, it is certain that, for all ordinary purposes, they may be represented by whole numbers of small amount; for, in the great majority of cases, the difference between any fraction and its nearest whole number falls within the limits of the errors necessarily attendant upon the present modes of experimenting. On these accounts we shall prefer it for our present purpose, which is more of general illustration than of accurate research.

The following are the equivalents, upon the hydrogen scale, of the several elements and their compounds which we have hitherto examined.

TABLE XXXIV. *Of Equivalents.*

ELEMENTS.

Hydrogen	1
Carbon	6
Oxygen	8
Nitrogen	14

PRIMARY COMPOUNDS.

Water	$H + O$	9	Lime	28
Ammonia	$N + 3H$	17	Potassa	48
Carbonic acid	$C + 2O$	22		
Protoxide of nitrogen	$N + O$	22		
Deutoxide of nitrogen	$N + 2O$	30		
Hypo-nitrous acid	$N + 3O$	38		
Nitrous acid	$N + 4O$	46		
Nitric acid	$N + 5O$	54		

SECONDARY COMPOUNDS.

Carbonate of Ammonia	$(C + 2O) + (N + 3H)$	39
Carbonate of Lime	$(C + 2O) + (L)$	50
Nitrate of Ammonia	$(N + 5O) + (N + 3H)$	71
Nitrate of Lime	$(N + 5O) + (L)$	82

§ 487. Before we proceed to examine some other important combinations of the four chemical elements which we have thus established, we will make two or three additional remarks upon nomenclature, and the system of what is called *chemical notation.*

Secondary compounds, or salts, derive their generic names from the acid which they contain; the termination *ic* being changed into *ate*, and *ous* into *ite*. Thus, a salt of the carbonic acid is a *carbonate;* of the nitric acid, a *nitrate;* of the nitrous acid, a *nitrite;*

of the hypo-nitrous acid, a *hypo-nitrite*. Their specific names are taken from those of their bases or oxides; as carbonate of ammonia, carbonate of lime, nitrate of ammonia, &c. When a metal, by different combinations with oxygen, forms more than one base, their salts are distinguished like the oxides, by the Greek ordinals: thus, the *proto*-nitrate of mercury indicates a combination of nitric acid with the protoxide of that metal; while the *per*-nitrate of mercury designates another salt, into the constitution of which the peroxide enters.

§ 488. Sometimes an acid enters into combination with a base in a greater proportion than that of single equivalents, the law of multiple proportions being still maintained; the excess of acid is indicated by Latin prefixes of quantity: thus, we have the *bi*-carbonate of ammonia, and the *sesqui*-carbonate of ammonia; the former containing two equivalents of the acid, and the latter an equivalent and a half.

On the other hand, the base may predominate over the neutral equivalent, when Greek prefixes are employed: thus, a combination of two equivalents of oxide of lead, and one of nitric acid, is called the *di*-nitrate of lead; of three equivalents, *tris*-nitrate of lead, &c.

§ 489. We have already, in two or three instances, had recourse to a kind of short-hand representation of the composition of bodies, formed of the initial letters of the several elementary substances connected together by Algebraical signs and numbers: the convenience of this system of abbreviation, in many cases, is obvious, and it is capable of considerable and advantageous extension, provided it be done upon a uniform and distinct plan.

Each element may be represented by the initial letter of its Latin name, adding a smaller letter of distinction where two or more begin with the same letter, and the sign may represent, at the same time, its relative combining proportion or equivalent number. Several equivalents of the same substance may be indicated by placing figures before the letter. Thus, N, will not only stand for nitrogen, but 14 nitrogen, and 4 N, will denote four equivalents of that element. The combinations of elements are most clearly expressed by the interposition of the Algebraic sign of addition +; thus, $N + 5\,O$, represents the nitric acid; and secondary combinations may be concisely, and at the same time fully described, by placing the elements of each proximate principle within brackets, or by connecting them together by a line. Thus, $(N + 5\,O) + (N + 3\,H,)$ represents the nitrate of ammonia, and

$\overline{C + 2\,O} + \overline{N + 3\,H}$, the carbonate of ammonia. A figure placed by the side of a letter, affects only the equivalent which the letter represents; but placed outside a bracket, affects all the symbols within: thus, $2\,(C + 2\,O) + (N + 3\,H,)$ signifies the bi-carbonate of ammonia. Other convenient abbreviations we shall notice as occasion may require.

Compounds of Oxygen and Hydrogen.

§ 490. Besides water, there is another compound of oxygen and hydrogen,—which is of very late discovery. Its preparation is founded upon the property which the peroxides of some metals possess of throwing off under the influence of an acid, one or more equivalents of their oxygen by which they are reduced to the state of protoxides, with which alone the acid can combine. Thus, if strong sulphuric acid, (or oil of vitriol,) be mixed with peroxide of manganese, pure oxygen gas may be collected from it to the amount of one equivalent, while only half the amount can be collected from the same quantity of the per-oxide, by heat, in the process which we formerly described (§ 410). A protoxide of manganese is thus produced, which forms a salt with the acid. In the same way the peroxide of another metal, *barium*, is incapable of uniting with acids, but passes under their influence into the state of protoxide, which readily enters into combination with them. When the process is conducted with the necessary precautions, particularly that of maintaining a low temperature, the oxygen which is set free, instead of escaping in the form of gas, unites with the hydrogen of the water, and constitutes a binoxide or peroxide of that element. The process is long, tedious and expensive, and it is not necessary for our purpose to enter upon its details: the product is very unstable, and can only be preserved in glass tubes surrounded by ice.

§ 491. Peroxide of hydrogen is a colourless, transparent liquid, inodorous and of a metallic taste. Its specific gravity is 1.452, and it consequently falls to the bottom of water, like syrup, but ultimately mixes with that liquid in any proportion. It evaporates much more slowly than water in vacuo, and, therefore, its solution may be concentrated under the receiver of an air-pump. It retains its liquid state at great degrees of cold. It has strong bleaching powers, instantly destroying vegetable colours, and whitens the skin and the tongue when brought into contact with them. It is decomposed with explosive violence by the sudden application of a temperature of 212°, and rapidly evolves oxygen even at 59°. The mere contact of most metals is sufficient to decompose it, and many peroxides act upon it with surprising energy. With oxide of silver, for instance, the decomposition is complete and instantaneous; oxygen gas is evolved so rapidly as to produce a kind of detonation; and such intense heat is disengaged that the glass tube in which the experiment is conducted becomes red-hot. Acids, on the other hand, have the property of rendering the compound more stable. Its careful analysis has proved it to be a definite compound of one equivalent of hydrogen and two equivalents of oxygen, or $H + 2O$ (115).

Compounds of Carbon and Oxygen.

§ 492. We have seen (§ 444) that the compound which is formed by the direct action of carbon and oxygen upon one another, is a gaseous acid in which the proportions of the two ingredients are per cent. 27.27 carbon, and 72.73 oxygen: this is the proportion of 3 : 8, and if this were the only combination of the two elements, 3 would be the equivalent of carbon upon the hydrogen scale. But according to another experiment (§ 481), 11 does not represent the equivalent of carbonic acid, but twice 11; for 56 parts of carbonic acid combine with 44 of ammonia; which is the proportion of 22 : 17. Hence, alone, we may suspect that carbonic acid contains in its constitution more than one equivalent of oxygen, and that there may be other compounds of the two elements.

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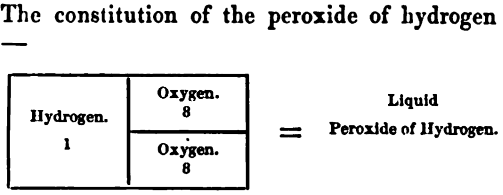
(115) The constitution of the peroxide of hydrogen may be thus represented:—



The proportions per cent. which would agree with this view would be:—

	Theory.	Analysis of Thenard.
Hydrogen	5.9 . . .	6.02
Oxygen	94.1 . . .	93.98
	100.0 . . .	100.00

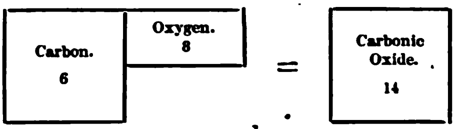
We can have no hesitation in here adopting the correction which theory affords to the results of experiment.

§ 493. If instead of exposing carbonate of lime, or limestone, alone to a high heat, in which case we have seen (§ 417) that we obtain carbonic acid, we mix it intimately in a powdered state with some substance which has a high affinity for oxygen, as charcoal or iron-filings, we shall by the same process obtain a gaseous product which may be collected over water.

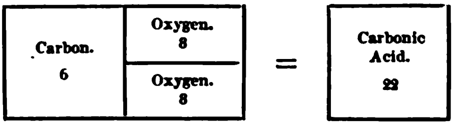
Carbonic oxide is considerably lighter than carbonic acid, 100 cubic inches only weighing 30.2 grains. It is speedily fatal to animals, extinguishes flame, but burns with a pale blue flame when mixed with atmospheric air. It is colourless and tasteless, but possesses a faint unpleasant smell. When a jet of it is burned in a cold receiver, no water is condensed, proving that it contains no hydrogen; but the product of the combustion precipitates lime-water. When two volumes of this gas, and one of oxygen, are exposed to an electric spark detonation ensues, and two volumes of carbonic acid are produced: proving that it contains half as much oxygen and the same quantity of carbon, as an equal volume of carbonic acid. In the latter substance, we have six carbon combined with sixteen oxygen; in the former, six carbon are combined with eight. Hence, we conclude 6 to be the equivalent of carbon; and as the inflammable gas has no acid nor alkaline properties, we denominate it *carbonic oxide*. In the process just described for making it, as the heat expels carbonic acid from the carbonate, the charcoal or the iron deprives it of half its oxygen (116).

---

(116) Carbon, as we have already stated (§ 423), has never in its elementary state been raised in vapour; but, nevertheless, in such of its compounds as assume the gaseous state, its constituent particles must have a gaseous arrangement. Upon the hypothesis that like all simple substances, except oxygen, it enters into combination in whole volumes of its vapour, we can calculate its specific gravity, and represent its combinations by the usual symbols; thus,—



and



As when carbon is burnt in oxygen gas, the latter undergoes no change

The formula of carbonic oxide is . . $C + O$
„ of carbonic acid . . . $C + 2O$

§ 494. There is another compound of carbon and oxygen, which stands intermediate in constitution between carbonic oxide and carbonic acid, but possesses very distinct and marked properties. It may be produced by acting upon almost every vegetable substance by nitric acid. By introducing into a retort one part of sugar and four parts of nitric acid, diluted with half its bulk of water, much deutoxide of nitrogen is given off; and upon evaporating about one-third of the liquid, the remainder, upon cooling, will shoot into white crystals. These may be purified by re-solution and crystallization, and will then be found to have the form of a right rhombic prism and to be intensely acid. They are soluble in nine parts of water at 60°; when carefully exposed to a temperature not exceeding 100° Fahrenheit, they lose about one-third of their weight of water, and fall into a white powder. Water thus combined with crystals in equivalent proportions, is called their water of crystallization, and they can part with it without interfering with their chemical characters. When heated to about 330° the acid sublimes, and upon cooling forms acicular crystals. Mixed with sulphuric acid and gently heated, it is rapidly resolved into equal volumes of carbonic oxide and carbonic acid. According to its careful analysis it is composed of one equivalent of each of these gases united in the crystals with three equivalents of water, and in the sublimed acid with one equivalent; without which, like the nitric acid, it cannot exist unless in combination with a base. The sulphuric acid from its strong attraction for water abstracts it entirely,

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of volume, and as 100 cubic inches of carbonic acid weigh 47.3 grains, if we deduct from this the weight of 100 cubic inches of oxygen, 34.6 grains, the remainder, 12.7 grains, will be the weight of 100 cubic inches of the vapour of carbon upon the view which we have just stated. Hence, the weight of 100 cubic inches of carbonic oxide would be :—

100 cubic inches vapour of carbon	12.7
50 cubic inches oxygen . .	17.3
	30.0

Which agrees with the result of direct experiment.

If we were to adopt the hypothesis that, like oxygen, carbon enters into combination in the proportion of half a volume of its vapour, it would be easy to modify the symbols and numbers accordingly.

and resolves the compound into its constituent gases. It enters into combination with ammonia and other bases in the equivalent proportion of 36, which agrees with the equivalent thus derived from its analysis: as $\overline{C + O + C + 2\,O} = 36$ (117).

It is called the *oxalic acid* as being a product of vegetation, and found in the *oxalis acetosella*, or wood sorrel, in combination with potassa.

§ 495. Oxalic acid may be artificially formed by a totally different process to that which has been just described; and perhaps nothing can better show the fixedness of chemical combinations than the contrast of the two. When sugar or saw-dust is heated to a temperature of about 400, in contact with four or five times its weight of potassa, they fuse together, swell up, and give out hydrogen. When the remaining mass is dissolved in water and gently evaporated, crystals of *oxalate of potassa* may be obtained from it. Under the influence of the alkali, at a high temperature, the carbon derives the oxygen which is necessary for its conversion into oxalic acid, from the decomposition of water and the evolution of hydrogen: under the influence of the nitric acid, it derives the same amount from the decomposition of the acid, and the evolution of deutoxide of nitrogen.

The oxalic acid very readily takes the oxygen which is necessary for its conversion into carbonic acid from other compounds, and thus, when its solution is poured into a solution of nitrate of mercury and some other metallic salts, the oxide is decomposed, and the metal is precipitated. One equivalent of oxalic acid is thus converted into two equivalents of carbonic acid, by the absorption of one equivalent of oxygen, $\overline{C + O + C + 2\,O} + O = 2\,(C + 2\,O)$.

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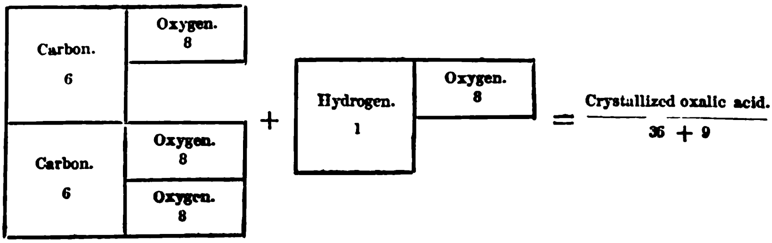
(117) The constitution of the oxalic acid, in volumes, may be thus represented:—



Compounds of Carbon and Hydrogen.

§ 496. A history of all the combinations of carbon would comprise the whole range of ORGANIC CHEMISTRY; and an account of all its compounds with hydrogen would be little less extensive. Upon this difficult and most interesting department of the science, it does not form any part of our present design to enter; but still it is impossible altogether to pass over the peculiar illustrations which this important element affords of the nature and action of the force of affinity. It will answer our purpose best, to take one of the best defined of the products of vegetation, *sugar*, and exhibit its equivalent constitution, and show what new arrangements may take place of its elements from changes in the balance of their affinities under the influence of various disturbing agents.

When exposed to a high temperature or to destructive distillation, vegetable substances are characterized by yielding large quantities of acetic acid in addition to the inflammable gases, water and carbonic acid, which are also given off; but their exact constitution cannot be inferred merely from the new compounds which are thus produced by the influence of heat.

§ 497. The principles upon which the analysis of organic substances is conducted are extremely simple. The process consists in furnishing them with as much oxygen, as is sufficient to convert the whole of their carbon into carbonic acid, and their hydrogen into water, by mixing them with oxide of copper and exposing them to a red heat; and in carefully collecting the products of such combustion in proper apparatus. By calculations founded upon the quantities carefully measured, it is easy to ascertain the quantities of the elements in the original compound (118). Pure crystallized sugar has thus been ascertained to be composed of:—

	Experiment.					Theory.
Carbon .	. 42.1	=	3 Equivalents.	18	=	40
Hydrogen	. 6.4	=	3 „	3	=	6.66
Oxygen .	. 51.5	=	3 „	24	=	53.34
	100.0	=		45	=	100.00

$(3\,C + 3\,H + 3\,O) =$ Sugar.

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(118) A convenient apparatus for the analysis of organic substances is represented in the next figure; A B represents the front of a double row of small spirit lamps, over which the tube, C D, is supported. Two or three grains of the substance to be examined, properly dried, are intimately mixed

§ 498. If we take a mixture of one part of sugar with four or five of water, and place it in a close vessel connected by a tube, with a pneumatic apparatus at a temperature of about 70°, the process of what is called *fermentation* may be determined in it by the addition of a small quantity of *yeast*, a foreign substance which itself undergoes no change in the process. A large quantity of carbonic acid will be evolved; the liquid will become less and less sweet till the sugar entirely disappears; and *alcohol* or spirit will be found in its place. Alcohol therefore is sugar, *minus* carbonic acid. According to the composition of sugar as we have just stated it, if one equivalent of its carbon pass off with two equivalents of its oxygen, two equivalents of carbon, three equivalents of hydrogen, and one equivalent of oxygen, would remain as the constituents of alcohol, which exactly agrees with the analysis of perfectly pure spirit. Thus:—

$$\overset{\text{Sugar.}}{(3\,C + 3\,H + 3\,O)} = \overset{\text{Carbonic acid.}}{(C + 2\,O)} + \overset{\text{Alcohol.}}{(2\,C + 3\,H + O)}.$$

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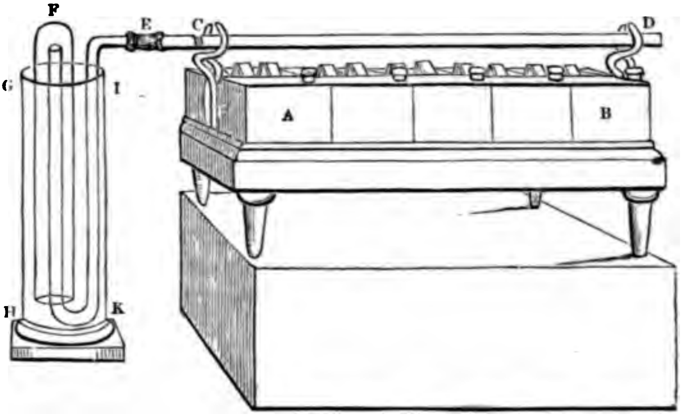
with about 200 grains of black oxide of copper, placed in the tube, and gradually brought to a red heat. The tube, C D, is connected at E, by means of a collar of caoutchouc, with another tube filled with dry muriate of lime, which having been previously weighed, stops all the vapour of water which passes over it; and will indicate by its increase



of weight, the quantity of hydrogen which has been combined with the oxygen of the oxide. The carbonic acid formed by the combustion of the carbon, and any nitrogen which the substance may contain, will pass together into the tube F, placed in the vessel of mercury, G H I K, and they may again be separated by absorption of the former, with solution of potassa, and the quantity of both may thus be estimated.

§ 499. Alcohol is a well-known inflammable liquid, which burns with a pale blue light, very like that of hydrogen. The products of its combustion are nothing but carbonic acid and water. It mixes with water in any proportion; but when perfectly anhydrous, its specific gravity is only .791. It boils at a temperature of 173°. The spirits of wine of commerce is alcohol, diluted by a variable proportion of water, from which it may be separated by distillation off quick lime.

§ 500. If the weak mixture of alcohol and water, formed in the first process of fermentation, be exposed to the air at a temperature of 65°, a further spontaneous change takes place; oxygen is absorbed and the alcohol gradually passes into acetic acid or vinegar. The oxygen acts by removing half the hydrogen, and by this process two equivalents of alcohol become converted into one equivalent of acid by the formation of three equivalents of water. Thus:—

$$\underset{\text{Alcohol.}}{2\,(2\,C + 3\,H + O)} + 4\,O = \underset{\text{Acetic Acid.}}{(4\,C + 3\,H + 3\,O)} + \underset{\text{Water.}}{3\,(H + O)}.$$

And this agrees with its direct analysis, and is moreover confirmed by its equivalent number 51, which corresponds with the proportion in which it combines with ammonia and other bases. The vapour of acetic acid when heated will burn with a pale blue flame, and yield nothing but carbonic acid and water. The specific gravity of the strongest acid is 1.063: when it contains one equivalent of water, with which it crystallizes at a temperature of about 45°. It is intensely sour; has a strong irritating odour, which is agreeable when sufficiently diluted, and is caustic. It readily combines with bases, and forms a distinct class of salts.

§ 501. If a measure of alcohol be mixed with two measures of sulphuric acid, placed in a retort, and a gentle heat applied, the mixture will very soon blacken, become thick, swell up, and give off gaseous matter, which may be collected over water. When this gas has been well washed with lime water, it has a specific gravity of about 980, and 100 cubic inches weigh nearly 30 grains. When quite pure it has but little odour, and is colourless. It burns in the atmosphere with a bright yellowish flame. It will not support life, and instantly extinguishes flame. When one volume of this gas is mixed with five of oxygen, the mixture will detonate by the electric spark. Three volumes only of the oxygen will be consumed, and two volumes of carbonic acid will be produced with water. Two volumes of carbonic acid indicate two equivalents of carbon, which must previously have been combined with two volumes of hydrogen, which now form water with the remaining volume of oxygen, and the whole must have been condensed into one volume. This deduction is confirmed by the specific gravity of the gas (119). It has been named *bi-hydro-carbon*, and is sometimes called *olefiant gas*, from a property to which we shall hereafter refer.

The action of the sulphuric acid upon the alcohol might be explained upon the hypothesis that, owing to its strong attraction for water, it removes the oxygen and hydrogen from that compound in which they exist in exact equivalent proportions. Thus:—

$$\begin{array}{ccccc} \text{Alcohol.} & & \text{Bi-Hyd. Carb.} & & \text{Water.} \\ (2\,C + 3\,H + O) & = & (2\,C + 2\,H) & + & (H + O). \end{array}$$

Olefiant gas may be decomposed by mere heat, and by passing it through tubes heated to a white heat, it will deposit the whole of its carbon, and become expanded into two volumes of pure hydrogen.

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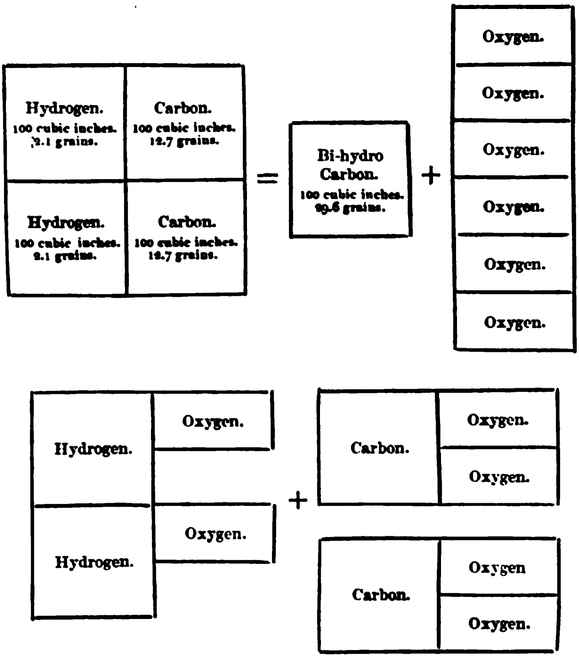
(119) The constitution of bi-hydro-carbon by volume, and the result of its decomposition by oxygen may be thus represented:—



§ 502. At a lower temperature, or a red heat, it parts with only half its carbon, without expansion of volume, and is converted into another compound of the same elements, named *sub-carburetted hydrogen.*

This gas is abundantly formed in stagnant pools of water by the spontaneous decomposition of vegetable matters, and may be procured by stirring up the mud, and collecting it in inverted bottles. It is also given out by certain seams of coal in coal-mines, and constitutes what the miners call the *fire-damp.* Coal when subjected to distillation in iron retorts gives off this gas mixed with the former in abundance, and the mixture constitutes the common coal gas which is now so largely employed for the purposes of illumination.

§ 503. Sub-carburetted hydrogen is a colourless, tasteless, permanent gas, soluble in very minute proportions in water, and inflammable. It burns with a yellow flame, but does not give out so much light as the bi-hydro-carbon; 100 cubic inches only weigh 16.94 grains. When mixed with atmospheric air, or oxygen, in certain proportions, it explodes with great violence upon contact with flame, or an electric spark. To decompose it completely, it is necessary to mix it with rather more than twice its bulk of oxygen, but exactly two volumes are taken up by one. Water and carbonic acid are produced, the latter being exactly equal to the original bulk of the inflammable gas. From these data, it is easily inferred to be a compound of two equivalents of hydrogen and one of carbon condensed into one volume (120).

§ 504. If, instead of mixing alcohol with twice its bulk of sulphuric acid, the two liquids be mixed in equal proportions by measure, and a gentle heat applied, a different series of changes takes place. The mixture will remain clear, and a very inflammable liquid will rise, which may be condensed in a refrigerated receiver, adjusted to the retort, into a light, colourless, very limpid liquid to which the name of *ether* has been given. When it has all distilled over, a fresh quantity may be obtained by the addition of more alcohol to the same acid. The acid, indeed, does not necessarily undergo any change during the process, except that of becoming gradually diluted with water, and in a properly arranged apparatus alcohol may be allowed to trickle into the retort, so as not to check the ebullition, but just to compensate the quantity which is removed by the change. If proper caution be used, and the adjustment of heat be properly attended to, any portion of alcohol may be etherized by the same portion of acid. The product of these operations must be rectified by mixing it with about a sixteenth of its weight of carbonate of potassa to absorb the water, and careful distillation from a water-bath.

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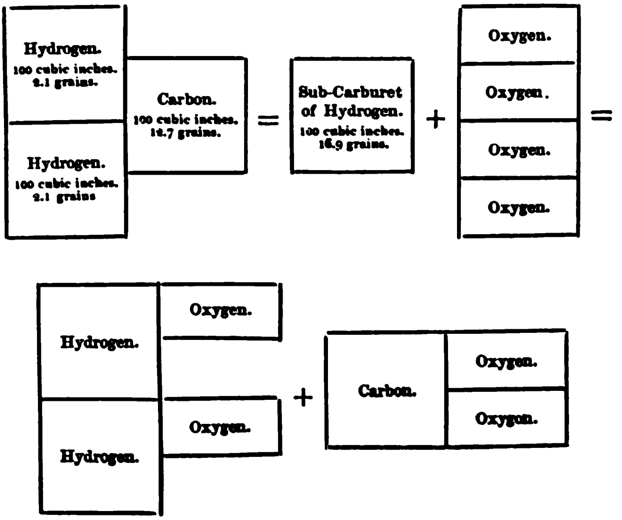
(120) The following diagram represents the constitution of sub-carburetted hydrogen, and the products of its detonation with oxygen gas:—

§ 505. Ether has a peculiar penetrating and agreeable odour, and a pungent, sweetish taste. It produces intoxication, even when its vapour is respired with the air. Its specific gravity when pure is 0.713. It is very volatile, and boils at a temperature of 96.5. At a temperature of 64°, the elasticity of its vapour is equal to 15 inches of mercury, and it is very heavy. Its specific gravity, with regard to air as 1, has been determined to be 2.58. When ignited it burns away with a bright flame, which deposits some carbon, and leaves no residue. The results of its analysis, by passing its vapour through red-hot oxide of copper, were as follow:—

Carbon . .	64.87	= 4 Equivalents.	24
Hydrogen . .	13.51	= 5 „	5
Oxygen . .	21.62	= 1 Equivalent.	8
	100.00		37



§ 506. The action of the sulphuric acid in this process may, therefore, be explained by supposing that, instead of taking the whole of the oxygen and hydrogen away, and thus evolving bi-hydro-carbon, it only removes half, and that thus two equivalents of alcohol are resolved into one equivalent of ether and one of water. Thus:—

$$\overset{\text{Alcohol.}}{2\,(2\,C+3\,H+O)} = \overset{\text{Ether.}}{(4\,C+5\,H+O)} + \overset{\text{Water.}}{\overline{H+O}}.$$

The ether itself, as its symbol indicates, being capable of being represented as another species of hydro-carbon united to water: or,—

$$(\overset{\text{Etherine.}}{\overline{4\,C + 4\,H}} + \overset{\text{Water.}}{\overline{H + O}}) = \text{Ether.}$$

To this compound of four equivalents of carbon and four of hydrogen, the name of *etherine*, or *quadri-hydro-carbon*, has been given.

§ 507. Now, all the common but highly interesting phenomena of *flame* are dependant upon the gradual combustion of the various elastic compounds of carbon and hydrogen, which we have just described; and we must turn aside for a short time to examine the constitution of this purest form of the classical element, *fire*, the properties of which could not have been satisfactorily illustrated without some previous acquaintance with these forms of matter. Flame is, in all ordinary cases, the combustion of explosive mixtures of inflammable gases or vapours with common air, in different proportions; and, when continuous, is maintained by an uninterrupted flow of these elastic fluids into the atmosphere, with which they slowly mingle. The mixture takes place chiefly at the surfaces of the gases in contact, and consequently the inflammation is only superficial; a sheet of flame surrounding, as it were, a reservoir of gaseous combustible matter. There are many ways of proving this; as by bringing a thin sheet of platinum foil down upon the flame of a large spirit-lamp, and thus truncating it, when a red-hot ring will appear upon the metal coincident with the edge of the flame, and testifying by its dark centre to the coldness of the interior (121).

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(121) In fig. 1 we are presented with a horizontal section of the flame of a candle, exhibiting the ring of light surrounding the interior dark part of the cone.

Fig. 2 exhibits a perpendicular section of the flame.

By inserting a small glass tube, *a b*, fig. 3, into the central dark part, If we ignite a piece of phosphorus in a metallic spoon, and plunge it into the body of a large flame, it will be instantly extinguished, owing to the want of oxygen to maintain its combustion; and it will thus afford a very striking proof of the point in question. The ordinary tapering form of flame is owing to the ascensional force of the heated gases rising in the cold surrounding medium.

§ 508. The quantity of light which flame emits is dependant upon the incandescence of minute particles of solid matter, which are thrown off during the combustion, and those flames whose immediate products are only gaseous matter give very little light. We have already noticed (§ 284) that an ignited jet of mixed oxygen and hydrogen, notwithstanding its great heating powers, is scarcely visible in day-light; but that solid bodies, such as platinum, and particularly lime, held in it, radiate light of great intensity. If some solid body, as oxide of zinc, or powdered charcoal, be projected through a flame of hydrogen it immediately becomes luminous.

The different forms of *hydro-carbon*, as the compounds of hydrogen and carbon are generically called, give out light in consequence of the particles of solid carbon which they disengage during their combustion, and they are luminous in proportion to the carbon which they contain. When the combustion is perfect, the solid matter itself is wholly burnt, and when there is an excess of oxygen but little light is given off; but if the quantity of oxygen be deficient, it is deposited in the form of soot. The perfection of a lamp, or candle, or other means of artificial illumination, consists in such a regular supply of air to the hydro-carbon employed, as is compatible with the gradual precipitation of the charcoal, and its complete oxidation.

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a, the inflammable gaseous matter of which it consists will ascend in it, and may be lighted so as to form a second flame at a distance from the first.

Fig.

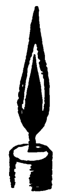

Fig. 2.

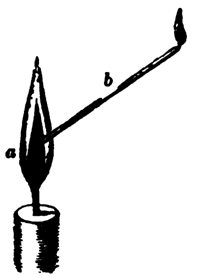

Fig. 3.

§ 509. For the purpose of increasing the heat of flames, and concentrating it upon any desired point, common air, and sometimes oxygen, is projected into their interior by means of what are called *blow-pipes*, or tubes of glass or metal prepared for the purpose. Combustion is thus carried on in the interior as well as the exterior of a flame, and its completeness is shown by the conversion of the smoky, red light of a lamp into a beautiful cone of pale blue light.

§ 510. The heat of flames, even of those which give least light, as of hydrogen and spirits of wine, is very great, and is essential to their existence. The combustion of many inflammable substances may be carried on at a temperature below that which is necessary to their inflammation. Thus, if a jet of the gaseous hydro-carbons be allowed to escape into the air, and a red-hot coil of platinum wire be introduced into it, the wire will be maintained at a red heat, and the gas will be consumed invisibly; but if the temperature of the wire be allowed to rise to a white heat, it immediately bursts into flame (122).

This being the case, it follows that flame may be put out by

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(122) Two arrangements for effecting this slow combustion are here represented.

In fig. 1 a small coil of fine platinum wire is placed upon the wick of a lamp, trimmed either with spirit of wine or ether. The lamp is lighted, and when the wire has become red-hot the flame is suddenly extinguished.

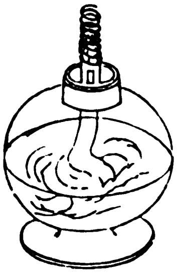

Fig. 1.

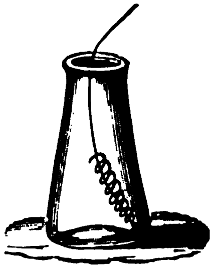

Fig. 2.

The wire will continue to glow as long as any of the combustible liquid remains to maintain the temperature by its slow combustion.

In fig. 2 we are presented with a coil of fine platinum wire, which has been previously heated by holding it in the flame of a spirit-lamp, and then plunged into a jar containing a little ether. It will continue to glow in the mixture of vapour and air till the ether is all consumed. If the temperature should rise to a white heat, the whole will burst into flame.

cooling the combining gases; and accordingly if we bring a cylinder of brass down upon a jet of burning vapour or gas, we shall diminish its volume, and possibly extinguish it by its good conducting power. If a stout metallic wire be held in a flame, a dark ring may be observed all round it, and it will never appear to touch it. A second wire held by the side of the first would increase the dark space, and the dark rings would coalesce. By multiplying the number of wires, or holding a piece of wire gauze in their place, the flame would appear to be entirely cut off on the top. The cooled gases, however, would still flow on in their course, and might be rekindled upon the upper side. Science is indebted to Sir Humphry Davy for the development of these principles, and the arts and humanity owe to the same illustrious philosopher their successful application to the invention of the miner's safety-lamp (123).

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(123) In fig. 1 we are presented with the appearance of a flame, upon which a piece of wire gauze has been brought down. The flame is cut off where it touches the gauze, and the exterior luminous circle is very visible. We seem to look down into the reservoir of inflammable gases which is inclosed by the sheet of ignited matter. The gases and smoke pass through, but are cooled and extinguished.

By presenting a flame to them on the upper side, they may be rekindled, as exhibited in fig. 2.

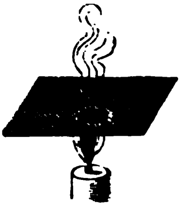


Fig. 1.

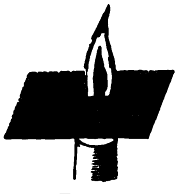
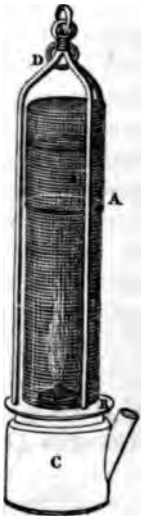


Fig. 2.



The "DAVY," or miner's safety-lamp, is here represented. A is a cylinder of wire-gauze with a double top, securely fastened to the brass rim, B, which screws on to the lamp, C. The whole is protected and rendered portable by the frame and ring, D. Gaseous matter freely penetrates through the meshes of the wire-gauze, and the combustion of the interior flame is maintained. Should an explosive mixture enter the lamp, it is kindled at the flame and burns, but the inflammation cannot pass the barrier of the cage, owing to its cooling the mixture below the temperature necessary to the process. Should the wires themselves, however, become white-hot, detonation of the exterior explosive atmosphere would take place.

§ 511. There is a curious fact with regard to chemical combination which derives its most striking illustration from some of the forms of hydro-carbon, namely,—that compounds may be formed of the same elements, in the same proportions to each other, which yet may differ essentially both in their physical and chemical properties. Such a constitution is indicated by the term *isomerism*, and such compounds are said to be *isomeric*. It will be expedient to examine two or three more of the numerous class of hydro-carbons to enable us to comprehend this fact with clearness.

§ 512. Fixed oils are natural compounds of carbon, hydrogen, and oxygen, in which the hydrogen greatly exceeds the proportion necessary for the conversion of their oxygen into water; by exposing them to a high temperature, as in the process of destructive distillation, fresh arrangements of their elements arise, and different forms of hydro-carbon are produced. When the gaseous products of this operation are subjected to a pressure of about thirty atmospheres, as was formerly done upon a very large scale by the *Portable Gas Company*, a part liquifies, but does not recover its aëriform state upon removal of the pressure. The liquid is limpid, of a brownish colour by transmitted, and green by reflected light. It has a nauseous smell, and its specific gravity is 0.821. Dr. Faraday examined this product, and found it to be a mixture of several definite compounds of carbon and hydrogen, differing in their volatility. By careful distillation and rectification he succeeded in separating and examining them.

The first was a colourless transparent liquid, having a specific gravity of 0.85; which, when cooled to a little below 32°, solidified and contracted considerably on cooling. It evaporated quickly in the air, and boiled at a temperature of 116°. Its vapour was very heavy, and its specific gravity as compared to air, 2.77. It burnt with a bright flame, and much smoke. By passing its vapour over heated oxide of copper, it was entirely resolved into carbonic acid and water, and the ratio of its carbon to its hydrogen was found to be 12 to 1, or 2 equivalents of carbon to 1 of hydrogen. But on examining the volume of oxygen required to combine with a definite volume of its vapour, it was found to be 7½ to 1, the product of which was 6 of carbonic acid; so that it would appear that the condensation of the hydrogen was 3 volumes into 1, and the constitution of the compound, 6 equivalents of carbon and 3 equivalents of hydrogen (124).

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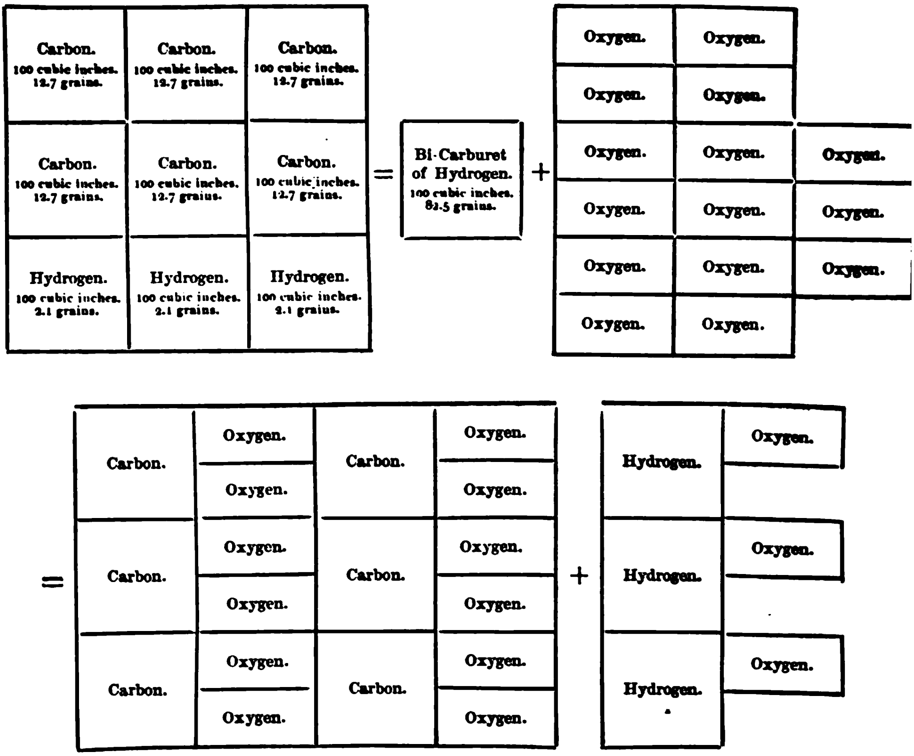
(124) The following diagram represents the constitution of this vapour, and the result of its decomposition by oxide of copper:—

§ 513. From this we are led to remark, that a definite specific condensation, or approximation of the particles of a compound, are no less essential to its constitution than a certain proportion of its heterogeneous principles. The ratio of 12 : 1, is the same as 36 : 3; but the specific union of 6 equivalents of carbon and 3 equivalents of hydrogen in a definite space is required to constitute the *bi-carburet of hydrogen*.

§ 514. Another portion of the condensed oil-gas was found to be capable of ebullition at common atmospheric temperatures, and when distilled by the heat of the hand, was collected as a gas over mercury. It burned with a brilliant flame, and had a specific gravity, compared with common air, as 1.963 to 1. When cooled to 0° Fahrenheit, it condensed into a liquid which had a specific gravity of 0.627, being the lightest known substance amongst solids and liquids.


Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Hydrogen. 100 cubic inches. 2.1 grains.
Hydrogen. 100 cubic inches. 2.1 grains.
Hydrogen. 100 cubic inches. 2.1 grains.
=
Bi-Carburet of Hydrogen. 100 cubic inches. 82.5 grains.
+
Oxygen.
Oxygen.
Oxygen.
Oxygen.
Oxygen.
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Oxygen.
Oxygen.
Oxygen.
Oxygen.
Oxygen.
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=
Carbon.
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Oxygen.
Carbon.
Oxygen.
Oxygen.
+
Hydrogen.
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Oxygen.
Hydrogen.
Oxygen.

By detonation with oxygen it was found that 1 volume of the vapour required 6 volumes of oxygen for perfect combustion, yielding 4 volumes of carbonic acid. The remaining 2 volumes of oxygen must of course have combined with 4 of hydrogen to form water. Hence it appears that 4 volumes of hydrogen were condensed into one with 4 equivalents of carbon, and that the ratio of the hydrogen to the carbon was 2 to 12, or the same as that of the bi-hydro-carbon (125). The essential difference, therefore, between *quadri-hydro-carbon*, or *etherine* as it is sometimes called, from its con-

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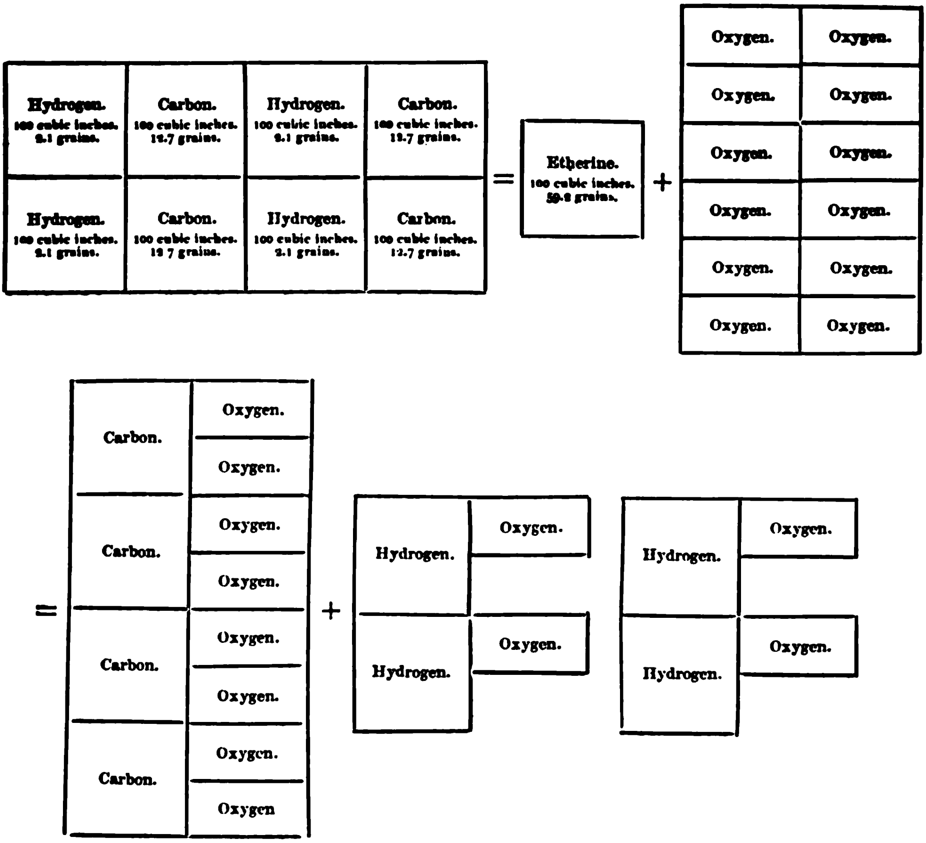
(125) The constitution of quadri-hydro-carbon, or etherine, by volume, may be thus represented, as well as the result of its combination with oxygen :—



This diagram should be compared with 119.

stituting the basis of ether (§ 506), and *bi-hydro-carbon*, consists in the state of their condensation.

§ 515. It is probable that there may be another compound of hydrogen and carbon, which is *isomeric* with these two, and in which the combining ratio would be the same, but in which the elements would be united in single equivalents, or in the proportion of 1 to 6.

§ 516. To illustrate this important law of isomerism still further, as well as to give another instance of the facility with which changes can be effected in organic substances which alter their very essence and identity, we will take another vegetable principle which is as definite in its constitution as sugar, and observe the different arrangement of its elementary particles which may be determined by altering the balance of their several affinities. This substance is *lignin*, or woody fibre. The bleached fibres of flax or hemp present it to us in its purest form; but from whatever source it may be derived, it is remarkably constant in its composition, and the analyses of the best chemists leave no doubt that it is composed of:

Carbon	50.00	=	3	Equivalents.	18
Hydrogen	5.56	=	2	„	2
Oxygen	44.44	=	2	„	16
	100.00				36

$$(3\ C + 2\ H + 2\ O) = \text{Lignin.}$$

§ 517. It agrees, therefore, with sugar, inasmuch as the oxygen and hydrogen which it contains are in exact proportion to form water, and it differs from it only in containing one equivalent less of each of those elements. So great a similarity of constitution diminishes our surprise in finding that lignin may very easily be converted into sugar.

If 24 parts of hempen cloth be triturated with 34 parts of sulphuric acid, it will acquire a mucilaginous consistence; and after 24 hours, will be found to be entirely soluble in water. Upon diluting this acid mixture with water, and boiling it for 10 hours, carefully renewing the water as it evaporates, it will become sweet, and upon neutralizing the acid with chalk and due evaporation, the liquid will afford crystals of sugar. In this process the acid undergoes no change whatever, but seems to exert an influence upon the heterogeneous attractions of the carbon, hydrogen, and carbon short of chemical affinity.

§ 518. When lignin, again, or rough wood, is exposed alone to a temperature of ignition, a large quantity of charcoal, as we have seen, (§ 420,) is left behind; and amongst the volatile products of its distillation there are two which are very definite and remarkable. The first is acetic acid, the properties and constitution of which, as derived from sugar and the acetic fermentation, have already been described, (§ 500,) and the second is a highly-inflammable volatile liquid, something resembling alcohol. When rectified by distillation from quicklime it is very limpid, and possesses a peculiar spirituous and aromatic odour. Its taste is hot and pungent. Its specific gravity about 0.800. It boils at 150°, and is very inflammable. It has been called *pyroxilic spirit.* It may be substituted for alcohol in many processes of the arts. According to its analysis it is composed of:—

Carbon	37.4	=	2 Equivalents.	12
Hydrogen	12.6	=	4 „	4
Oxygen	50.0	=	2 „	16
	100.0			32

(2 C + 4 H + 2 O) = Pyroxilic spirit;

which differs from alcohol by the addition of one equivalent of oxygen and one equivalent of hydrogen.

§ 519. When one part of this spirit is distilled with four of sulphuric acid abundance of gas is evolved; which, when collected over mercury, is found to consist of a peculiar body mixed with carbonic and sulphurous acids, which may be abstracted by potassa. It has a specific gravity of 1.61, is colourless, of an ethereal odour, and burns with a blue flame like that of alcohol. It is soluble in water, which takes up 37 times its volume at 65°. Its analysis shows it to be a compound of:—

Carbon	52.2	=	2 Equivalents.	12
Hydrogen	13.0	=	3 „	3
Oxygen	34.8	=	1 Equivalent.	8
	100.0			23

(2 C + 3 H + O) = Hydrate of methylene.

It is, therefore, isomeric with alcohol, and the difference in their respective properties must depend probably upon the different densities of their hydro-carbon. It has been called *hydrate of* *methylene*. The term *methylene* being taken to indicate the peculiar form of hydro-carbon, which in this compound is supposed to be united to water.

$$\underset{\text{Methylene.}}{(2\,C + 2\,H)} + \underset{\text{Water.}}{(H + O)} = \text{Hydrate of Methylene.}$$

§ 520. Another and distinct species of hydro-carbon is presented to us in the liquid which is commonly known by the name of *naphtha*. It is a natural as well as an artificial product. It is obtained in considerable quantity from the shores of the Caspian Sea and from parts of Italy, and it is one of the products of the destructive distillation of pit-coal and the manufacture of coal-gas. Its specific gravity varies from 750 to 850. It has a strong, bituminous, penetrating odour, which is not unpleasant in the natural variety, but very disagreeable in the artificial. It does not congeal at 0°. It burns with a strong sooty flame. When pure it is not acted upon by potassium, and is therefore used to protect that metal from oxidation. The density of its vapour is about 2.8. According to its best analysis, it is a compound of six equivalents of carbon and five of hydrogen condensed into one volume of the vapour (126).

$$(6\,C + 5\,H) = \text{Naphtha.}$$

§ 521. The last species of hydro-carbon, to which it will be necessary to refer at present, is also a product of the distillation of coal: it has been named *naphthalin*. It passes over with the other volatile products, and is first obtained in transparent flakes of a reddish-brown colour. These may be purified by slow sublimation

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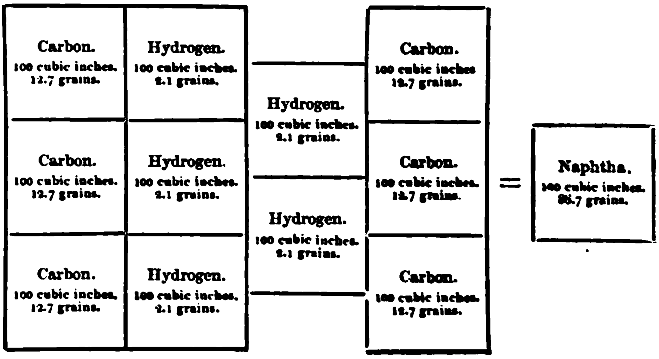
(126) The constitution of naphtha may be thus represented:—



from powdered charcoal, and are then colourless, and possess very little odour. When heated it has a very peculiar smell, something like that of the flower of the narcissus very much concentrated. It is heavier than water, and unctuous to the touch. It fuses at 200°, and at 400° boils, and may be distilled with little change. It crystallizes as it cools, and evaporates at common temperatures; when inflamed it gives off a very dense black smoke. The specific gravity of its vapour is 4.49. Its composition, as derived from its analysis, is ten equivalents of carbon and four equivalents of hydrogen, all condensed into one volume (127).

$$(10\,C+4\,H) = \text{Naphthalin.}$$

Compounds of Carbon and Nitrogen.

§ 522. As we have had recourse to the vegetable department of Creation for the first materials for the formation of the compounds of carbon and hydrogen, so we must turn to the animal department for the preparatory steps for the combination of carbon and nitrogen. Animal bodies differ from vegetable, as a class, by containing large quantities of nitrogen in their constitution; and they are characterized by yielding carbonate of ammonia when exposed alone to a high temperature, or to destructive distillation. The process of their analysis is conducted in the same way as that of vegetable bodies, and their nitrogen which escapes the action of the oxide of copper is easily measured on separating it from the carbonic acid by means of potassa.

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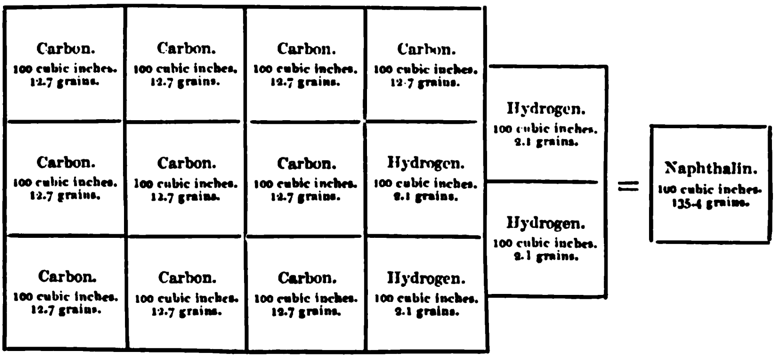
(127) The following is the constitution of the vapour of naphthalin by volume :—


Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Hydrogen. 100 cubic inches. 2.1 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Hydrogen. 100 cubic inches. 2.1 grains.
=
Naphthalin. 100 cubic inches. 135.4 grains.
Hydrogen. 100 cubic inches. 2.1 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Carbon. 100 cubic inches. 12.7 grains.
Hydrogen. 100 cubic inches. 2.1 grains.

§ 523. If, instead of exposing animal substances alone to a temperature of ignition, we bring them under the concurrent influence of potassa and metallic iron, a different adjustment takes place of the affinities of their constituent particles. Thus, by projecting a mixture of potassa and dry animal matters, such as horns or hoofs, in the proportion of two parts of the former to five of the latter, into a red-hot iron pot, and stirring them with an iron rod, they will assume a pasty form, and give off a quantity of fœtid vapours. When these cease, the mixture must be allowed to cool, and then thrown into water. The solution, upon being properly clarified, will, upon evaporation, yield crystals of a yellow saline body, called *ferro-cyanate of potassa.*

§ 524. The peculiar substance which has thus been united to the potassa may next be transferred to oxide of iron by double elective affinity. For this purpose its solution is poured into a solution of green vitriol (oxide of iron combined with sulphuric acid); when, after a short time, a deep blue precipitate takes place, which is known as a pigment by the name of *Prussian blue.* When washed in dilute acid and dried, it possesses a peculiarly rich and intense colour; is insipid, inodorous, and insoluble in water. Sulphate of potassa is at the same time formed, and remains in solution.

§ 525. Another transfer is yet necessary before we can proceed to insulate the primary compound of which we are in search. By boiling two parts of Prussian blue with one of peroxide of mercury in seven or eight of water, the compound gradually loses its colour, and a solution is obtained which, after filtration, deposits on cooling, white crystals in the form of quadrangular prisms, of a metallic taste and very poisonous. They go by the name of *cyanide of mercury.*

§ 526. Upon exposing these crystals to a moderate heat, they first give off water of crystallization, and fall into a gray powder. When this anhydrous cyanide of mercury is exposed to a red heat in a glass retort, it turns to a deep brown colour, metallic mercury distils over, and gaseous matter is given off which may be collected over mercury.

When generated in a confined space, it liquifies at a pressure of between three and four atmosperes at the temperature of 45°. The liquid is colourless and limpid, and, when relieved from pressure, speedily evaporates with the production of intense cold.

The gas is colourless, and has a penetrating very peculiar smell. When a lighted taper is dipped into a jar containing it it is immediately extinguished, but the gas itself burns in the air with a beautiful purple flame edged with blue, which is very characteristic. 100 cubic inches weigh 55.5 grains. It sustains the application of a high heat without undergoing decomposition. Water dissolves about 4½ times, and alcohol 23 times its bulk of this gas.

It may be detonated with oxygen; and its analysis may be effected in this way, or by passing it over red-hot oxide of copper. One volume mixed with two of oxygen, and fired by the electric spark, afford exactly two volumes of carbonic acid and one volume of nitrogen. Whence it appears to be a compound of two equivalents of carbon and one of nitrogen. According to the principles of the scientific nomenclature, its name would be *bi-carburet of nitrogen;* but it is more frequently denominated *cyanogen*, from its entering into the composition of the blue compound with iron, which we have already noticed (128).

$$(2\,C + N) = \text{Cyanogen.}$$

§ 527. The brown matter which is left in the retort after the decomposition of cyanide of mercury, is an isomeric compound

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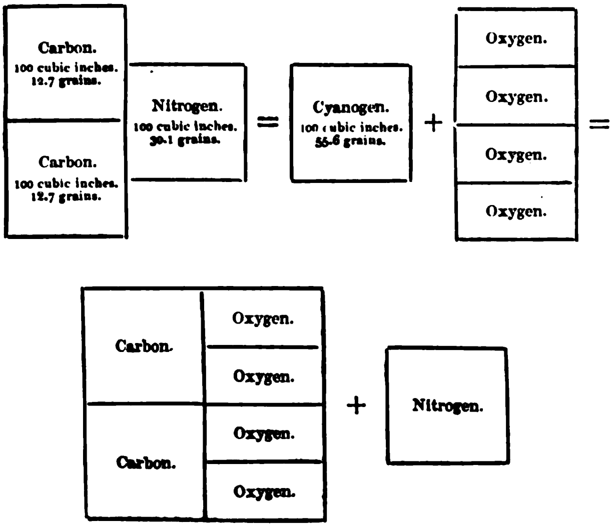
(128) The constitution of cyanogen, and the results of its analysis by oxygen may be thus represented:—



of carbon and nitrogen in exactly the same proportions. It is also formed when a solution of cyanogen in alcohol is left to time, and is sometimes produced in charring animal substances. It has been called *para-cyanogen*. When heated in the air, part of the carbon burns away, and a residue is obtained which consists of one equivalent of carbon and one of nitrogen, which may be denominated the *proto-carburet of nitrogen*.

§ 528. A more intimate acquaintance with the primary compounds of carbon has lately discovered to the view of chemists a mode of secondary combination, which is very different from that of acids with bases. It seems to be almost peculiar to this Proteus of the elementary substances, and its development is of the utmost consequence to a clear understanding of organic compounds, of which carbon constitutes the basis. Its first illustration may be best taken from the combinations of cyanogen.

§ 529. Cyanogen is neither acid nor alkaline in its nature, and it has little disposition to enter into combination with metallic oxides; but it has a remarkable tendency to combine with elementary substances in a manner perfectly analogous to that of the simple gaseous substances which we have been examining. When potassium, for example, is heated in cyanogen gas, the metal combines with the gas with great energy, and becomes incandescent. The saline mass which results must obviously be a ternary compound of carbon, nitrogen, and potassium: or $2\,C + N + P$; but it may be more advantageously regarded as a binary compound of cyanogen and the metal, or $(2\,C+N) + P$. Similar compounds may be formed with all the metals, and from their analogy to the class of oxides they are denominated *cyanides*. The cyanide of mercury, which we described as the source from which cyanogen is procured, is another instance of this binary combination, which was formed, not by direct combination with the metal, but by elective affinity from its oxide.

§ 530. It also forms compounds with the non-metallic elements, which are of high importance and interest inasmuch as they are of an acid quality, and are capable of entering into secondary combination with the bases. We will illustrate this by shortly examining its combinations with hydrogen and oxygen.

Compounds of Cyanogen.

§ 531. The compound of cyanogen and hydrogen cannot be obtained by the direct action of the two substances, but may be formed by double elective affinity, by passing some of the compounds of hydrogen over cyanide of mercury. Such a compound may be obtained by acting upon a combination of sulphur and iron with dilute sulphuric acid, in which case, instead of pure hydrogen, a definite compound of hydrogen and sulphur is evolved, which we shall hereafter examine.

By passing a current of this gas over the cyanide of mercury in a horizontal glass tube, double decomposition ensues; the sulphur combines with the metal, and the cyanogen with the hydrogen; and the latter compound, being very volatile, is easily driven over by a gentle heat into a cooled receiver placed for its reception.

It is a colourless liquid of a strong pungent odour, something resembling, when diluted, that of peach-blossoms. Its taste is said to be acrid; but it is so extremely poisonous, that a drop falling upon the arm of a man has been known to occasion death. Great care should be taken not to inhale its vapour. It is extremely volatile, and generates so much cold during its evaporation that a drop placed upon a piece of glass will spontaneously freeze. It boils at a temperature of 80°. Its vapour takes fire upon the approach of flame, and when mixed with oxygen, may be detonated by the electric spark. It feebly reddens litmus paper. Its specific gravity at 45° is 0.705, and that of its vapour 0.947.

§ 532. Two volumes of the vapour require two volumes and a half of oxygen for their perfect combustion; and two volumes of carbonic acid, with one volume of nitrogen and water, are the products. These results indicate two equivalents of carbon, one of hydrogen, and one of nitrogen, as the elements of the acid. When potassium is heated in this vapour, cyanide of potassium is formed, and hydrogen, equal to half the volume of the acid, is disengaged. It is therefore a compound of equal volumes of cyanogen and hydrogen. The results of the analysis may thus be stated:—

$$\begin{array}{lll}
\left.\begin{array}{lr}\text{Carbon} & 44.4\\ \text{Nitrogen} & 51.8\end{array}\right\} & = 1\ \text{Equivalent of Cyanogen.} & 26\\
\begin{array}{lr}\text{Hydrogen} & 3.7\end{array} & = 1\quad ,,\qquad\quad \text{Hydrogen.} & 1\\
\hline
\qquad\qquad 100.0 & & 27
\end{array}$$

§ 533. It is sometimes called Prussic acid as being derived from the Prussian blue; but the scientific nomenclature distinguishes the class of acids, into the composition of which hydrogen enters, by the prefix *hydro*,—and hence it is also called the *hydro-cyanic acid* (129).

§ 534. Hydro-cyanic acid forms a salt by combining with ammonia, in their respective equivalents 27 and 17: it crystallizes in cubes or small prisms, and is very volatile.

The hydro-cyanic acid also enters into combination with the oxygen bases; but the binary compound of cyanogen and the metal is the general result, as the hydrogen of the acid and the oxygen of the base are in exact proportion to form water together. Thus, cyanide of potassium is formed by neutralizing potassa with hydro-cyanic acid, and when red oxide of mercury is shaken up with the same acid it loses its colour, and bi-cyanide of mercury is found in solution.

§ 535. Cyanogen also generates an acid by combination with oxygen; but the process by which it may be formed and insulated from its combinations is circuitous. By exposing a mixture of per-oxide of manganese and the yellow salt which we described as

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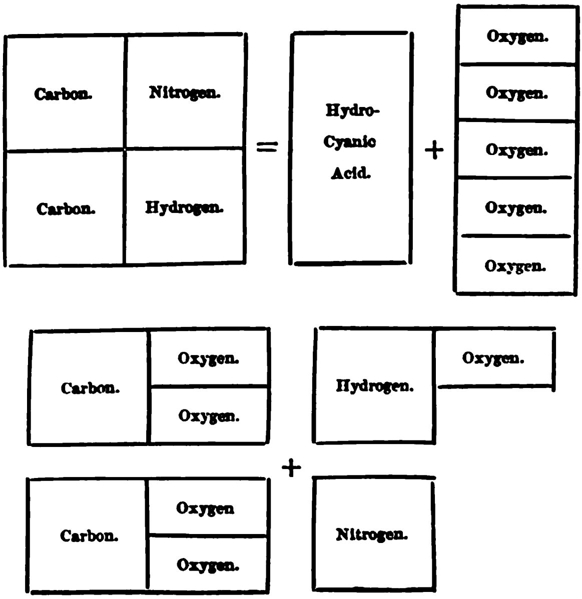
(129) This diagram represents the constitution of hydro-cyanic acid, and the results of its detonation with oxygen.



formed by the action of potassa upon animal substances to a dull red heat, in an iron pot, and boiling the resulting compound in alcohol, another salt may be obtained in tabular crystals consisting of the acid in question, or *cyanic acid*, in combination with potassa, and which may therefore be distinguished by the name of *cyanate of potassa.*

The acid may be transferred from the potassa to the oxides of lead, mercury, or silver, by double decomposition with the salts of those metals with which it forms insoluble compounds, and from these it may be disengaged by sulphuretted hydrogen, the sulphur of which combines with the metal, and the hydrogen with its oxygen. It is thus obtained as a sour liquid, smelling something like vinegar, and very prone to spontaneous decomposition.

§ 536. According to its analysis, the cyanic acid is a compound of one equivalent of cyanogen and one equivalent of oxygen. It is readily converted into carbonate of ammonia, by merely boiling its solution, or that of any of its salts; a change which an attentive consideration of its symbol, in connexion with that of water, will readily explain; for one equivalent of cyanic acid, with three equivalents of water, are exactly equal to one equivalent of bi-carbonate of ammonia: thus,—

$$\overset{\text{Cyanic Acid.}}{(\overline{2\,C + N} + O)} + \overset{\text{Water.}}{3\,(H + O)} = \overset{\text{Carbonic Acid.}}{2\,(C + 2\,O)} + \overset{\text{Ammonia.}}{(N + 3\,H)}.$$

§ 537. An *isomeric* compound of cyanogen and oxygen may be formed, whose properties are very different from those of the cyanic acid. By boiling together a solution of nitrate of mercury or nitrate of silver in alcohol, an effervescence takes place; and a gray powder gradually subsides from the solution, which is the compound in question in combination with the oxide of the metal employed. It is a very dangerous fulminating powder, which detonates violently by heat or percussion, and sometimes by the slightest friction. The acid in union with the oxide has hence been distinguished as the *fulminic acid.* The gases evolved by the explosion of the fulminates of silver or mercury are carbonic acid and nitrogen, and their exact analysis proves the fulminic acid to have exactly the same equivalent composition as the cyanic acid.

§ 538. The elementary character and analogies of cyanogen are fully maintained, as we shall have occasion hereafter to point out, in all its combinations with those non-metallic elements which have not yet passed under our review.

Compounds of Hydro-Carbon.

§ 539. The different species of hydro-carbon present us with innumerable instances of analogous secondary combination. They appear to be all capable of acting the part of simple substances with the non-metallic elements, and in their combinations with compound bodies do not perform the function of bases, or constitute saline compounds. They replace elementary substances in composition, and elementary substances may, on the other hand, be substituted for them.

§ 540. Their action upon sulphuric acid is peculiar; and they enter into composition with it so as to form, not salts, but new acids.

When naphthalin is fused with half its weight of sulphuric acid, a red crystalline mass is obtained which is soluble in water. When carbonate of baryta is added to the solution, it is decomposed, and the base is divided between two salts which are formed, the one with sulphuric acid, which is wholly insoluble, and the other with the new acid, which remains in solution. From this the baryta may be precipitated by the careful addition of sulphuric acid. The aqueous solution of *sulpho-naphthalic acid*, as it has been named, is of an acid taste, mixed with bitter. It reddens the blue colour of vegetables, and forms salts with the different bases, all of which are soluble in water. When concentrated by evaporation with heat in the open air, it becomes brown, thick, and ultimately solid, but rapidly attracts moisture from the air. When concentrated in vacuo under the receiver of the air-pump, it may be obtained in the form of a white solid, which, when perfectly dry, is hard and brittle, but rapidly deliquesces in the air. At 212° it melts and crystallizes upon cooling.

§ 541. Its analysis shews it to be a compound of 2 equivalents of sulphuric acid and 2 equivalents of naphthalin.

$$\underset{\text{Naphthalin.}}{2\,(10C+4H)} + \underset{\text{Sulphuric Acid.}}{2\,(S+3O)} = 208.$$

It enters into combination in this equivalent proportion, and the quantity of the bases required to neutralize it is, therefore, the same as would be required to neutralize half the sulphuric acid in its constitution.

§ 542. When sulphuric acid again is brought to act upon alcohol, as in the process for making ether, it immediately determines the formation of, and enters into combination with *etherine*, in the proportion of two equivalents of the acid to one of the quadri-hydrocarbon, and a new acid is formed, to which the name of the *sulpho-vinic acid* has been given. Its composition therefore is:—

$$\underset{\text{Etherine.}}{(4C+4H)} + \underset{\text{Sulphuric Acid.}}{2\,(S+3O)} = 108.$$

It resembles the sulpho-naphthalic acid in its constitution, and like it requires half the amount of any base for its neutralization which would be necessary for the neutralization of the sulphuric acid in its constitution.

The sulpho-vinic acid may be obtained in an insulated state, or rather in combination with water only, by the decomposition of *sulpho vinate of baryta or lead*, both of which are soluble salts, by sulphuric acid, which precipitates their bases in an insoluble form. When concentrated by evaporation in vacuo, it may be obtained in the form of a colourless, sour liquid, of the specific gravity = 1.319. It is decomposed by a gentle heat. At a high temperature the sulpho-vinate burns with flame, and leaves a residue of the bi-sulphate of the base.

§ 543. The formation of the sulpho-vinic acid is probably a necessary preliminary step in the formation of ether; for it is by the agency of the sulphuric acid thus exerted that the etherine is first formed from the alcohol. It is afterwards evolved in combination with water as ether; ether being capable of being represented, as we have seen, as a hydrate of etherine (§ 506).

§ 544. Etherine, again, is capable of combining with sulpho-vinic acid when its acid properties are entirely neutralized. Such a compound is obtained by carrying the distillation of a mixture of sulphuric acid and alcohol beyond the point at which ether comes over. An oily-looking liquid is then obtained, which was formerly known by the name of *oil of wine;* when well washed and purified it has a pungent aromatic flavour. It is composed, according to its analysis, of:—

$$\underset{\text{Etherine.}}{2\,(4C+4H)} + \underset{\text{Sulphuric Acid.}}{2\,(S+3O)}$$

§ 545. Etherine also enters into combination with other acids, and the compounds are known by the name of *ethers*, which are distinguished by the names of the acids which enter into their composition.

Oxalic ether may be procured by distilling 1 part of alcohol, 2 of sulphuric acid, and 1 of oxalic acid. An oil-like liquid is obtained, mixed with alcohol and ether, which settles to the bottom of the receiver. It must be separated from the lighter liquids, which float above it, and may be purified by boiling it with powdered oxide of lead. It has a specific gravity of 1.093 at 45°, it boils at 360°, and is inflammable. It posseses an aromatic odour, and is but little soluble in water, but is readily taken up by alcohol. When in contact with water it is speedily resolved into oxalic acid and alcohol. It consists of:—

Carbon . . .	49.31	= 6 Equivalents.	36
Hydrogen . . .	6.85	= 5 „	5
Oxygen . . .	43.84	= 4 „	32
	100.00		73

And its constitution may be represented as:—

$$\begin{array}{ccccc} \text{Etherine.} & & \text{Oxalic Acid.} & & \text{Water.} \\ (4C+4H) & + & (2C+3O) & + & (H+O); \end{array}$$

or one equivalent of etherine united to one of oxalic acid, and one of water.

Acetic ether, may be prepared by distilling a mixture of 63 parts of strong acetic acid, and 17 of sulphuric acid, with 100 parts of alcohol. The product must be rectified by redistillation from lime. It boils at 105°, burns with a yellowish flame, and the evolution of acetic acid. It is lighter than water, and possesses a peculiar agreeable odour. Its ultimate analysis gives the following results:—

Carbon . . .	54.55	= 8 Equivalents.	48
Hydrogen . . .	9.09	= 8 „	8
Oxygen . . .	36.36	= 4 „	32
	100.00		88

Which are equivalent to:—

$$\begin{array}{ccccc} \text{Etherine.} & & \text{Acetic Acid.} & & \text{Water.} \\ (4C+4H) & + & (4C+3H+3O) & + & (H+O); \end{array}$$

or one equivalent of etherine, one of acetic acid, and one of water.

§ 546. Similar combinations of that species of hydro-carbon to which the name of methylene has been given $(2C+2H)$ may be made by analogous processes, and perfectly different from those which we have just examined of etherine $(4C+4H)$.

§ 547. It is not consistent with our plan to follow this subject further at present; but we shall take an opportunity of showing how these *radicals*, (as compound bodies which enter into combination after the manner of simple substances are called,) combine with the remaining non-metallic elements as the latter pass under our review.

§ 548. Before we proceed to this examination we must, however, make a few observations upon the definite combinations of water, which sometimes plays the part of one of these compound radicals. We have already seen that it enters into the composition of certain salts, in its equivalent proportion, or some multiple of it, and that it then goes by the name of *water of crystallization* (§ 494). Sometimes a salt will spontaneously part with one equivalent at ordinary temperature, in a dry atmosphere, and then loses its transparency and crystalline texture, and falls into a powder: it is then said to *effloresce*. Most salts give off the whole of their water at a high temperature. Some salts lose their colour when anhydrous, (as the sulphates of copper and iron,) and recover it again upon having it restored, but their more salient chemical properties are not altered by the change.

§ 549. Water again enters into definite combination with the oxides of the different metals, which are then called *hydrates*, or are said to be *hydrated*. Thus 40 parts of potassium combine with 8 parts, or 1 equivalent, of dry oxygen, to constitute 48 parts of potassa; but when brought into contact with water, 48 parts of potassa unite with 9 parts of water to constitute the *hydrate of potassa*. So intimate is this union, that no degree of heat is capable of driving off the water; although on entering into combination with acids the alkali often separates from it.

§ 550. We have also seen that water combines in its equivalent proportions with certain acids; which, in fact, are not capable of existing in a state of insulation from bases unless their elements are bound together by its attraction. This is the case with the nitric and the oxalic acids (§ 462 and 494); when they enter into secondary composition with the bases they are, however, capable of throwing off the water, and combine in their simple equivalent ratios.

Water is also capable of replacing, and of being replaced by elementary substances, or other radicals, in various secondary combinations.

§ 551. Our examination of the classical elements has thus brought us acquainted:—1st, With the leading characters of the *metals* as a class of simple substances, connected together by the strongest analogies. 2ndly, With those of four non-metallic elements, *oxygen*, *hydrogen*, *nitrogen*, and *carbon*, separated from one another, and from the preceding class by differences as strong as it is possible to imagine; and we have been led to examine some of their compounds, both primary and secondary, with the leading object of founding *clear ideas* of the laws of chemical combination upon *distinct facts*. Further illustration of this subject is still necessary: and it is also necessary that we should become acquainted with other species of matter, both simple and compound, before we can be in a condition fully to appreciate the connexion of the physical forces, and their concurrence to the production of chemical phenomena.

To attain this object, we may proceed to examine the remaining *non-metallic elements*, which are only nine; and such of their principal compounds as may tend to illustrate the formation of the infinite variety of substances, which may be formed from these few materials restricted within the narrow limits of combination which we have already defined.

§ 552. A scientific arrangement of the subject, even if our present imperfect knowledge would admit of it, is beyond our present design, which is to ascend from the known to the unknown by the easiest and most natural gradation. We will therfore select for the next subjects and instruments of illustration, a group of these elementary forms of matter which are connected together, like the class of metals, by the strongest analogies, and of which to state the modes of combination of one is to lay them down for all. They have, moreover, one common origin,—namely, the waters of the ocean; from the saline contents of which, or of the ashes of vegetables which grow upon its shores, they are all derived by similar processes. They do not exist in the insulated state in nature, but are the educts of chemical science, and two of them of very recent discovery. They have received the trivial names of *chlorine*, *bromine*, and *iodine*.

Chlorine.

§ 553. Chlorine may be obtained by mixing three parts of pure culinary salt, which is derived either from sea-water or rock-salt, with one part of peroxide of manganese, and pouring upon them in a retort two parts of sulphuric acid diluted with an equal weight of water. By the action of a gentle heat, a gas is given off, which may be collected in bottles over hot water, and preserved by carefully expelling all the water, and closing them with greased stoppers.

Water of the ordinary atmospheric temperatures dissolves about twice its volume of the gas, and mercury rapidly combines with it. It possesses a yellowish-green colour, from which it derives its name, an astringent taste and a most noxious suffocating odour; all of which qualities it communicates to its aqueous solution. When received into the lungs, its action is extremely painful and injurious. By subjecting it to a pressure of four atmospheres at 60°, it may be condensed into the liquid state. In its gaseous form under ordinary circumstances, it is considerably heavier than common air, 100 cubic inches weighing between 76 and 77 grains. It undergoes no change by being passed through porcelain tubes intensely heated, nor by a succession of electric sparks, and it has resisted all attempts to decompose it.

The flame of a taper introduced into it continues to burn with a dull red light, throwing off a dense black smoke. Even when the wick is merely glowing, the flame will be rekindled; but the combustion is maintained by the hydrogen only, the carbon being entirely precipitated. Phosphorus spontaneously ignites in it, and burns with a pale white flame, indicative of the absence of any solid matter, and several of the metals in a finely divided state, or in thin leaves, burn spontaneously; and in this way tin, copper, zinc, and antimony, exhibit very beautiful appearances.

§ 554. The primary compounds of chlorine and the metals are denominated *chlorides*, and their multiple combinations are distinguished, like the oxides, as *proto-chlorides*, *deuto-chlorides*, *per-chlorides*, &c. They have points of considerable resemblance to the oxides, and like them, some of them have the property of combining with others of the same class, in the manner of acids and bases. These have sometimes been named *chloro-salts*, but are most conveniently distinguished as *double chlorides*.

When the metal sodium is heated in chlorine, it burns vividly, and produces a compound which has all the properties of culinary salt; which is therefore a chloride of sodium.

§ 555. Chlorine when mixed with the vapour of water as it is usually obtained, or in solution, has strong bleaching powers upon vegetable colours, and a solution of indigo in sulphuric acid, is on this account frequently employed to test its presence. When perfectly dry, however, it is without action even upon the delicate blue colour of litmus. Whence it has been conjectured that its property of bleaching may be derived from its combining with the hydrogen of a part of the water, and the formation of deutoxide of hydrogen. It has also strong anti-septic properties, and from its strong affinity for some of the elements of animal substances, destroys contagious matters and bad odours.

The compounds which chlorine forms with the non-metallic elements and radicles are various, important, and instructive.

Chlorine and Hydrogen.

§ 556. A mixture of chlorine and hydrogen will remain in the dark without change, but if exposed to day-light the two gases will unite slowly, and in the direct light of the sun, suddenly and with detonation. When mixed together exactly in the proportion of equal volumes, and fired by the electric spark in the apparatus formerly described (102), a bright flash takes place; and if the tube be opened over mercury, no change of volume will be perceptible: but if it be opened over water, the liquid will dissolve the gas, rush in with violence and fill the tube.

The destruction of the green colour of the mixture will indicate the essential change which has taken place with the extrication of light and heat; as well as its different action upon vegetable colours. Instead of bleaching it will now be found to redden the blue colour of litmus, which property it communicates to its solution, which, moreover, is intensely sour. In short, the compound has all the properties of a powerful acid. It is called, according to the scientific nomenclature, *hydro-chloric acid*, but it has long been known by the name of *muriatic acid.* It may readily be obtained from sea-salt by the action of strong sulphuric acid. The gas which is given off in great purity must be collected over mercury.

§ 557. Hydro-chloric acid is colourless, of a very pungent odour, and intensely acid. Its attraction for water is so great, that when a little escapes into the air, a white cloud is instantly formed from the condensation of the atmospheric vapour. It extinguishes flame and is incombustible, it is also perfectly irrespirable: it may be liquified at a pressure of 40 atmospheres, by generating it in a confined space. Water at the temperature of 40 will dissolve about 480 times its volume, and thereby increases its bulk and its specific gravity from 1 to 1.210. The solution is largely employed in the arts, and may be produced by passing the gas immediately into water, or by adding a sufficiency of water to the sulphuric acid and distilling. Acid of the specific gravity of 1.111 may be distilled without change. The solution when pure is perfectly colourless, and possesses the smell and other properties of the gas (130).

§ 558. Hydro-chloric acid may be decomposed by several of the metals which combine with its chlorine and disengage its hydrogen. Tin, lead, or potassium, heated in the gas are converted into chlorides, and leave half the original bulk of the gas of pure hydrogen. Thus, its analysis exactly agrees with its synthesis by volumes, and from its specific gravity it is easy to calculate that 36 parts by weight of chlorine are combined with one of hydrogen, and that its equivalent number is consequently 36, and that of the acid 37 (131).

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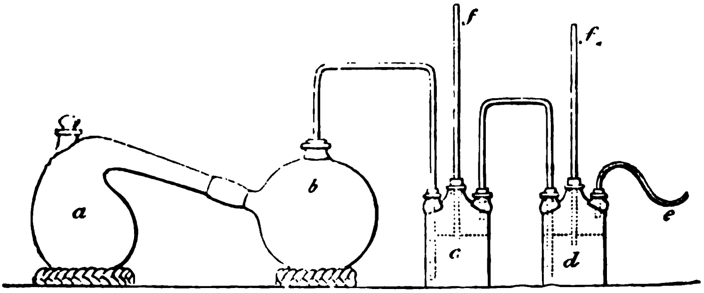
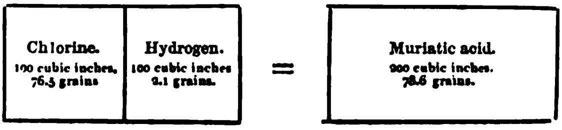
(130) The saturation of water with the more soluble gases, is carried on in what is called *Woulfe's Apparatus.* *a* is a tubulated retort for containing the materials for the extraction of the gas; *b* is a receiver communicating by a bent tube with the three-necked bottle, *c*, which is connected also by a tube with *d*. The bottles are about half filled with water; when that in *c* is saturated, the gas passes into *d*, and afterwards through the tube *e*, which may be connected with the pneumatic trough. The safety tubes, *ff*, prevent the water being forced by the pressure of air into *b*, in case absorption should be too rapid. They dip only about half an inch under water, so that the air readily enters by them, and compensates the absorption.



(131) The constitution of muriatic acid may be represented thus:—



§ 559. The law of equivalent proportions is beautifully illustrated by the reaction of hydro-chloric acid upon metallic oxides. According to the general view which we have given of the mutual action of acids upon bases, it might be expected that a simple combination of the two would take place, and that when muriatic acid was neutralized by soda, a *muriate of soda* would result; and when the compound is in solution in water, there is nothing to contradict the hypothesis which is founded upon the strong analogy of other acids. But when separated from water by evaporation, we find that we have in this secondary compound exactly the same substance as is produced by the primary combination of metallic sodium and chlorine. The hydrogen of the acid and the oxygen of the base being in equivalent proportions, have combined together to form water (132).

There is no ambiguity in the case of the combination of the muriatic acid and ammonia; the result must obviously be a muriate of ammonia, but in many instances of the action of muriatic acid upon other bases, it is perhaps impossible to decide whether the product be a muriate or a chloride. This acid, for example, will combine with oxide of barium or baryta: and when this base is heated in the gas it becomes red-hot, water is formed, and a grey substance is produced which is exactly the same as may be formed by the action of chlorine upon it, in which case oxygen is evolved. There is here no question that the result is a *chloride of barium.*

If on the other hand the compound be dissolved in water, or if carbonate of baryta be decomposed by liquid hydro-chloric acid and the solution carefully evaporated, flat, four-sided crystals will be obtained, which are permanent in ordinary states of the atmosphere, but effloresce from loss of water of crystallization in dry air. They contain two equivalents of water which may be wholly expelled, and dry

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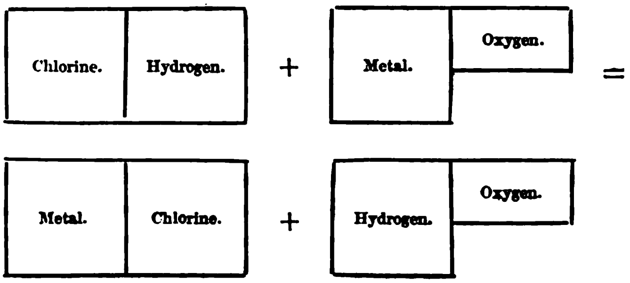
(132) The general case of the action of muriatic acid upon a metallic oxide may be thus represented :—



chloride of barium will remain. Now it is obvious that this crystallized salt may be regarded as a compound of muriatic acid and baryta, and one equivalent of water of crystallization; while, on the other hand, there is no good reason for affirming that it may not be a hydrated chloride.

The symbolic representation of these two views will render this perhaps clearer: for,—

$$\overset{\text{Chloride of Barium.}}{(B + C^{l})} + \overset{\text{Water.}}{2(H + O)} = \overset{\text{Oxide of Barium.}}{(B + O)} + \overset{\text{Muriatic Acid.}}{(C^{l} + H)} + \overset{\text{Water.}}{(H + O)}$$

The last view supposes that when the dry chloride of barium is dissolved in water, an equivalent of the latter is decomposed, the hydrogen of which combines with the chlorine, to form the hydrochloric acid and the oxygen with the metal to constitute the baryta. That chlorides are capable of effecting this decomposition may be shown by examples, in which there can be no ambiguity; as when chloride of antimony is dropped into water, muriatic acid is the result, and an insoluble hydrated oxide of the metal which is precipitated.

§ 560. The exact adjustment of equivalent proportions is again shown in the action of muriatic acid upon the oxides of such metals, as constitute more than one salifiable base, as for instance, the protoxide and the deutoxide of mercury, in the first of which 200 parts of the metal are combined with eight of oxygen or one equivalent, and in the second, with sixteen or two. When the protoxide is subjected to the action of the acid, 37 parts or one equivalent is decomposed; one equivalent of water is formed, and one equivalent of proto-chloride, which is exactly similar to the primary combination which takes place at ordinary temperature, between 200 parts of mercury and 36 of chlorine. When the deutoxide, on the contrary, is acted upon by muriatic acid, 74 parts or two equivalents of the latter are decomposed, two equivalents of water are composed, and one equivalent of the bi-chloride which is exactly the same as the bi-chloride formed by the action of chlorine upon mercury at a high temperature, and consists of 200 parts of mercury and 72 of chlorine.

§ 561. When the peroxides of metals, on the other hand, whose protoxides alone constitute bases, are acted upon by muriatic acid, one equivalent only of chlorine combines with the metal, the equivalent hydrogen of which forms water with one equivalent of the oxygen of the peroxide, while the remainder of the oxygen combines with the hydrogen of another portion of the acid, and sets the chlorine free. It is in this way that chlorine can advantageously be collected by the direct action of a strong solution of muriatic acid upon peroxide of manganese.

The same observations apply to all the class of hydro-acids; another of which, the hydro-cyanic acid, has been already described (§ 534).

The hydro-chloric acid is the only known compound of chlorine and hydrogen.

Compounds of Chlorine and Oxygen.

§ 562. Chlorine and oxygen are connected together by many points of resemblance; and are deficient in that marked opposition of characters which renders the force of affinity most efficient. Their modes of combination with hydrogen and the metals are similar, and chlorine supports the combustion of these elements as well as oxygen. For every *oxide* there is a corresponding *chloride*, and they are both equally opposed to hydrogen; which only in two or three instances, as exceptions to a general rule, shows a slight attraction for metals. There is another striking analogy between the two in their relation to electrical forces, which will be hereafter pointed out.

No combination of chlorine and oxygen can, therefore, be obtained by the direct action of the two elements; but several can be formed by double decompositions and recompositions, all of which are unstable, and some of them decomposable even with violence by slight changes of temperature.

§ 563. Upon agitating a mixture of one part of deutoxide of mercury, with twelve of water in a bottle filled with gaseous chlorine, the gas is rapidly absorbed; a white powder is deposited, which is chloride of mercury, and a liquid compound of oxygen and chlorine remains in solution; but care should be taken that some of the red colour may remain to ensure the complete absorption of the gas. The liquid must be filtered and distilled in vacuo: it is then a solution of the first compound of chlorine and oxygen, to which the name has been given of the *hypo-chlorous acid.* It may be separated from its water of solution by throwing up a portion into an inverted jar of mercury, and then passing into it through the metal pieces of fused nitrate of lime. The salt rapidly abstracts the water, and a gas is obtained of a deeper yellow colour than chlorine, of a strong penetrating odour, and decomposable by mercury from the contact of which it is preserved by the saline solution. It requires to be very cautiously dealt with; for a very slight elevation of temperature, such as the heat of the hand, is sufficient to decompose it with the extrication of light and heat; and when absorbed into the pores of charcoal, or even blotting paper, by the force of adhesion, this violent separation of the gases takes place. The direct solar says will also resolve it into its elements without detonation. When mixed with hydrogen it explodes violently by the electric spark. Its analysis shows it to consist of one volume of chlorine, and half a volume of oxygen condensed into one, or one equivalent of each. This would make its equivalent $36 + 8 = 44$, but from some of its combinations it is probable that the proportion in which it enters into secondary composition, may be double this or 88 (133). Its formula is $2 (C^l + O)$.

The solution of hypo-chlorous acid is pale yellow; it has a peculiar odour and an acrid taste. It attacks the cuticle more energetically than nitric acid, and stains it of a reddish brown colour. All the metals which have a strong attraction for oxygen become oxidated by it and evolve chlorine; but silver combines with the chlorine and evolves oxygen.

§ 564. By submitting other oxides to the action of chlorine, it may be made to combine with a higher proportion of oxygen. By passing a current of the gas into a solution of potassa, one portion combines with the metal, forming a chloride of potassium, while another portion unites with the oxygen which is displaced and constitutes an acid, which is called the *chloric acid.* This, again, combines with some of the unchanged potassa, forming a salt, to which the name of *chlorate of potassa* has been given. It separates spontaneously, from its little solubility, in brilliant rhomboidic tables.

Chloric acid may also be obtained in the free state, or rather in

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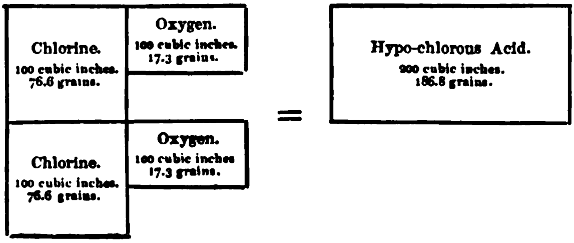
(133) The composition of the hypo-chlorous acid, by volume, is therefore probably:—



union with water alone, without which, or a base, it cannot exist, by passing a current of chlorine through oxide of silver suspended in water. Chloride of silver, which is insoluble, is precipitated, and chloric acid remains in solution. It may be freed from any excess of chlorine by boiling. It is a sour, colourless, liquid; and forms no precipitate in any metallic solution. Hydro-chloric acid and chloric acid mutually decompose one another: water is formed, and the chlorine of both set free. Chloric acid consists of,—

Chlorine . . .	47.4	= 1 Equivalent.	36
Oxygen . . .	52.6	= 5 Equivalents.	40
	100.0		76

Its formula is $(C^{l}+5\,O)$.

§ 565. The character of the salts of this acid may be taken from that of the *chlorate of potassa.* When exposed to a low red heat it fuses, gives off its oxygen, and chloride of potassium remains. We have already mentioned it as a convenient source of pure oxygen (§ 410). It acts very energetically upon most inflammable substances, and when triturated with sulphur, charcoal, or phosphorus, detonates strongly with the evolution of light and heat, owing to the decomposition of the acid.

§ 566. Another compound with a less proportion of oxygen, may be formed by the action of sulphuric acid upon chlorate of potassa. Its preparation should only be attempted in small quantities; as by moistening about 50 grains of the salt with a few drops of strong acid, when a solid mass will be obtained of an orange colour. By introducing this mass into a small retort, and gradually warming it by a water bath kept below the boiling point, a yellowish-green elastic fluid passes off, which is rapidly dissolved by water, but may be collected in small tubes over mercury. Its odour is peculiar, and not nearly so suffocating as that of chlorine. 100 cubic inches weigh about 72 grains. It explodes at a temperature below 212° with great violence, and the evolution of a bright light. Two volumes are thus expanded into three, two of which are oxygen, and one chlorine, so that its composition must be:—

Chlorine . . .	52.9	= 1 Equivalent.	36
Oxygen . . .	47.1	= 4 Equivalents.	32
	100.0		68

Its formula is $(C^{l}+4\,O)$.

Its proper name is *peroxide of chlorine*, but by some chemists it has been called the *chlorous acid.* Its solution possesses a deep yellow colour, and an astringent corrosive taste. It bleaches very strongly.

§ 567. From the same source that we obtain the peroxide of chlorine, we may also procure chlorine in a still higher degree of oxidation than in the chloric acid; for, after the oxide has been obtained by the action of the sulphuric acid upon the chlorate of potassa, there remains a white saline mass, which is a mixture of two salts, namely, *bi-sulphate of potassa* and *per-chlorate of potassa*, which may be easily separated by solution and crystallization, as the former is much more soluble than the latter.

By distilling the per-chlorate of potassa with its own weight of sulphuric acid, diluted with about a fourth part of water; the *per-chloric acid* separates in white vapours, which condense in the form of a colourless liquid. It is the most stable of all the compounds of the two elements. It may even be obtained in the form of crystals by distillation with sulphuric acid, which abstracts all its water. It is not decomposed by hydro-chloric acid. It is constituted of:—

Chlorine . . .	39.2	= 1 Equivalent.	36
Oxygen . .	60.8	= 7 Equivalents.	56
	100.0		92

Its formula being $(C^{l}+7\,O)$.

Compound of Chlorine and Nitrogen.

§ 568. There is but one known compound of chlorine with nitrogen, which cannot be obtained by the direct action of the two elements; and it is as unstable as its compounds with oxygen which we have just described. It may be formed by the action of chlorine upon any of the salts of ammonia. When gaseous chlorine is passed into ammoniacal gas, it decomposes it with so much energy that the gas inflames: muriatic acid is formed, which combines with another portion of the ammonia, and nitrogen is left. By passing the same gas into an aqueous solution of the alkali, or by mixing the solutions of the two gases, pure nitrogen may be collected. When chlorine, however, is passed into warm solutions of muriate or nitrate of ammonia, the ammonia is still decomposed, but the nitrogen is not given off in the free state, but in combination with another portion of chlorine. The same compound is also formed by suspending a crystal of ammoniacal salt in a solution of hypochlorous acid.

It is an oily-looking liquid which falls to the bottom of the solution in which it is generated, and should not be experimented upon in quantities larger than a grain of mustard seed; even then it should be handled with extreme caution. It is the most powerfully-explosive compound known. Its specific gravity is 1.653, and it does not become solid at great degrees of artificial cold. At about a temperature of 200° it detonates spontaneously, and the mere contact of some combustible substances causes it to explode. When a globule is touched with olive-oil or turpentine, the concussion which is produced is so great as to shatter any glass or earthern-ware vessel in which the experiment is made. Metals, resins, and sugar, do not ordinarily cause its decomposition; but most greasy substances, phosphorus, naphtha, potassa, and many others cause it to detonate.

The products of its decomposition are chlorine and nitrogen, and its composition has been inferred to be:—

Nitrogen . . .	11.5	= 1 Equivalent.	14
Chlorine . . .	88.5	= 3 Equivalents.	108
	100.0		122

It has been named *chloride of nitrogen*, and its formula is $(N+3\,Cl)$.

§ 569. The nature of these detonations, and of the light and heat which are thus given off during the separation of elements which are mostly characterized by having but a feeble mutual affinity, is by no means understood; if, indeed, we can be said to understand the evolution of light and heat at all. At present the usual explanation of the phenomena of combustion does not seem applicable to them. The compounds of nitrogen are particularly liable to such energetic decompositions, which is the more remarkable, as this element appears to be particularly inert in its combining powers.

Compounds of Chlorine with Carbon and Hydro-carbon.

§ 570. When a mixture is made of two parts of chlorine to one of bi-hydro-carbon by volume and ignited, muriatic acid is formed, and the whole of the carbon is deposited in the form of a dense black smoke: but if a mixture of equal volumes of the two gases be allowed to remain over water, complete condensation takes place. The result of the combination is a yellow liquid, looking like an oil, but possessing a peculiar odour and sweet taste. It is volatile, and may be distilled without change. It was from the formation of this substance that the bi-hydro-carbon was formerly called *olefiant gas*. It possesses, however, very different properties from those of oil, and more nearly approaches ether in character. Indeed its composition ranks it with those compounds of hydro-carbon and acids which have been already described (§ 545). It may properly be called the *chloride of hydro-carbon*. Its specific gravity at 45° is 1.22, it boils at 152°, and at 49° its vapour is capable of supporting a column of mercury of 24.66 inches. It burns with a green flame, and gives out copious fumes of muriatic acid and much soot. It is composed of one volume of chlorine and one of olefiant gas, or by weight of:—

Carbon . .	24	= 2 Equivalents.	12	Bi-hydro-carbon.
Hydrogen .	4	= 2 „	2	
Chlorine .	72	= 1 Equivalent.	36	
	100		50	

Formula, $(\overline{2\,C+2\,H}+C^{l})$.

§ 571. When the hydro-chloride of carbon is exposed in an atmosphere of chlorine to the direct rays of the sun it is decomposed: muriatic acid is formed by the abstraction of the hydrogen, and the carbon remains in combination with chlorine alone. The *per-chloride of carbon* thus obtained is a transparent, colourless, solid, having very little taste, and possessing an aromatic odour resembling that of camphor. Its specific gravity is 2.0. It is very brittle, and a non-conductor of electricity. It is volatile at common temperatures, and sublimes in very transparent colourless crystals. It melts at 320°, and boils at 360° Fahrenheit. It is scarcely combustible, but when held in the flame of a spirit-lamp it burns with a red flame, and gives off much smoke and fumes of muriatic acid. It is but little soluble in water, but is readily taken up by alcohol, and may be obtained in crystals from that liquid upon careful evaporation. The results of both its analysis and synthesis concur in its being a compound of:—

Carbon	10	= 1 Equivalent.	6
Chlorine	90	= 1½ Equivalents.	54
	100		60

Formula, $(2\,C+3\,C^{l})$.

§ 572. This compound may be converted into a *proto-chloride* by simply passing its vapour through an ignited glass tube, containing fragments of glass or rock crystal, to increase the heated surface. Chlorine escapes, and a fluid passes over, which may be separately condensed.

It is limpid and colourless; does not assume the solid form, even at 0° of Fahrenheit, and is volatilized at a temperature between 160° and 170°. Its specific gravity is about 1.5. It may be distilled without change, but undergoes decomposition at a full red heat. It may be mixed with alcohol, ether, and oils, but not with water. It is not combustible, except when held in the flame of a lamp, when it burns with a yellow light, and gives off much smoke, mixed with muriatic acid. Its analysis shows it to be composed of:—

Carbon	14.3	= 1	Equivalent.	6
Chlorine	85.7	= 1	„	36
	100.0			42

Formula, $(C + Cl)$.

§ 573. Quadri-hydro-carbon, or etherine, forms a compound with chlorine, which is a liquid somewhat resembling the hydro-chloride of carbon, but is not identical with it. When treated with excess of chlorine in the light of the sun, muriatic acid is produced and chlorine disappears, but no chloride of carbon is formed: thus affording another proof that isomeric bodies are endued with very different specific properties.

Compound of Chlorine and Cyanogen.

§ 574. When the bi-cyanide of mercury is moistened with water and exposed, in the dark, to the action of chlorine in a closed vessel, bi-chloride of mercury is formed, and a compound of cyanogen and chlorine in vapour. By exposure to a temperature of 0° Fahrenheit the *chloride of cyanogen* solidifies. In this state, after absorbing any moisture from it by fused muriate of lime, the bottle is filled with mercury, inverted, and heat applied, when it again rises in the elastic state. At a temperature of about 6°, or under a pressure of four atmospheres at 60°, it assumes the liquid state. It is soluble in water, but to a greater extent in alcohol and ether. Its vapour is very deleterious when breathed, and irritates the eyes. 100 volumes of the vapour consist of 50 volumes of cyanogen and 50 of chlorine, and it is a compound of:—

Carbon	19.4	Cyanogen	=	2 Equivalents.	12
Nitrogen	22.6		=	1 Equivalent.	14
Chlorine	58.0		=	1 "	36
	100.0				62

Formula, $(\overline{2C+N}+C^{l})$.

Bromine.

§ 575. In the manufacture of culinary salt from sea-water, after the processes of evaporation and crystallization, an uncrystallizable residue remains, which goes by the name of *bittern*. It contains in solution a salt of exactly analogous constitution to the chloride of sodium, but in which another non-metallic element is united with the metallic basis. It may be separated by passing chlorine into the solution, which, from superior affinity, combines with the metal, and a deep yellow colour is immediately developed, and a strong peculiar odour. By distillation and passing the vapour, as it rises, over muriate of lime, to detain the water, a few drops may be obtained of a volatile liquid, of a red colour, which will fill the receiver with vapours resembling that of the nitrous acid. It has been called *bromine*.

It is better obtained by agitating the liquid, after the action of the chlorine, with ether, which exercises a strong solvent power upon the bromine and separates it from the aqueous solution. It may be separated from the ether by the action of potassa, which forms with it a *bromide of potassium* and a *bromate of potassa*, exactly in the same way that chlorine and chlorate of potassa are formed under similar circumstances (§ 564). By evaporation to dryness and exposure to a dull red heat, the bromate is easily converted into bromide. This salt may then be treated exactly in the same way as chloride of sodium in the generation of chlorine, with oxide of manganese and sulphuric acid. Red vapours are given off by distillation, which condense into blackish-red drops in the cooled receiver.

§ 576. Bromine is a fluid of a hyacinth-red colour, when viewed by transmitted light. At a temperature a little below 0° Fahrenheit, it suddenly congeals, and is very brittle. Its odour is extremely disagreeable and intense, its taste unpleasant, and very powerful. It is very poisonous. It corrodes the skin, and stains it yellow, but not permanently. Its specific gravity is nearly 3. It is very volatile, gives off red vapours at common temperatures, and boils at 116.5.

Light which has been transmitted through the vapour of bromine much diluted with common air, presents, when analyzed by the prism, a spectrum interrupted by more, probably, than 100 equidistant lines; as the vapour becomes denser, the blue end of the spectrum disappears, and the lines in the red part become more distinct. In this extinction of the blue rays it presents a marked analogy with chlorine. The arrangement of the lines is quite different from that of the lines presented by an atmosphere of nitrous acid (§ 461), although the two vapours cannot be distinguished from each other by colour.

A taper will not burn in its vapour, but, when mixed with air, it alters the tint of the flame. It is soluble in water, alcohol, and particularly in ether. It does not redden, but destroys the colour of litmus, and even of indigo. It forms a crystalline combination with water at a temperature of 32° Fahrenheit, and the form of the crystals is octohedral. They are of a red tint, and continue permanent even at the temperature of 50°.

Bromine produces a characteristic deep yellow colour when mixed, even in small quantities, with cold solution of starch.

Compound of Bromine and Hydrogen.

§ 577. When the vapour of bromine and hydrogen are mixed together, they do not react upon one another at ordinary temperatures, even when exposed to the direct light of the sun; neither does the mixture explode by the passage of an electric spark: but if a coil of red-hot platinum wire be suspended in it, combination goes on upon its surface, and enough heat is disengaged to maintain the process.

A colourless gas is thus obtained, possessed of strong acid properties. It may also be obtained in larger quantities by the action of sulphuric acid upon the bromide of potassium. It is called the *hydro-bromic acid.* It is rapidly absorbed by water, but may be collected and preserved over mercury. It produces dense white vapours when it escapes into the air, from its combination with aqueous vapour, and it possesses a strong irritating odour. Its solution in water is colourless, and possesses the principal properties of the gas.

The hydro-bromic acid is decomposed by chlorine, which combines with its hydrogen to form hydro-chloric acid, and the bromine is set free. Potassium decomposes it, combines with the bromine, and disengages exactly half its volume of pure hydrogen. The weight of 100 cubic inches of the acid is about 85 grains.

50	cubic inches of Hydrogen . .	1.06
50	„ Bromine . .	84.00
100		85.06

Or it consists of:—

Hydrogen . .	1.255	= 1 Equivalent.	1	
Bromine . . .	98.745	= 1 „	78	
	100.00		79	(134.)

Formula, (H + B).

Compound of Bromine and Oxygen.

§ 578. We have already stated (§ 575) that, when bromine is passed into a solution of potassa, a bromide of potassium and a bromate of potassa are formed; and the same adjustment of the affinities of the elements concerned takes place with other bases. Thus a bromide of barium and a bromate of baryta may be procured, the former of which may be easily separated from the latter from its superior solubility. The bromic acid may be disengaged from the bromate of baryta by sulphuric acid, which forms an insoluble compound with the base, and leaves the acid in solution. It possesses scarcely any odour, but has an acid taste and reddens, and gradually destroys, the blue colour of litmus. It is similar in its constitution to the chloric acid, and is composed of:—

Bromine	66.1	= 1 Equivalent.	78
Oxygen	33.9	= 5 Equivalents.	40
	100.0		118

Formula, (B + 5 O).

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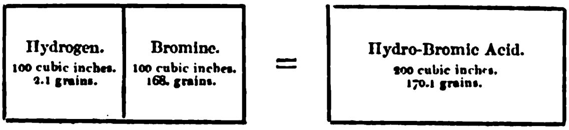
(134) The constitution of the hydro-bromic acid by volume is, therefore:—



Most of the salts of the bromic acid, like those of the chloric, when mixed with sulphur or other combustibles, detonate with a blow, and scintillate upon hot charcoal.

Iodine.

§ 579. The ashes of sea-weeds, called *kelp*, which are largely produced on the western coast of Scotland, and were formerly very much used in the manufacture of soap, afford another undecomposed substance, which in its properties, and modes of extraction and combination, strongly resembles chlorine and bromine.

After the separation of the carbonate of soda from the kelp, an uncrystallizable residue remains, containing a salt exactly analogous to the chloride and bromide of sodium. By mixing per-oxide of manganese with it, and pouring upon it sulphuric acid, beautiful violet vapours make their appearance, which condense upon cooling into crystalline plates of the colour and lustre of plumbago. These crystals may easily be collected and dried between folds of blotting-paper. The substance is called *iodine.*

§ 580. It is a soft, friable, solid, at the ordinary temperature of the atmosphere, and assumes the form of brilliant scales or plates. It crystallizes as an elongated octohedron or as rhomboidal plates. It possesses a hot and acrid taste, but is very sparingly soluble in water. It is poisonous in large doses, but is much used in medicine. At 60° Fahrenheit it is nearly five times as heavy as water. It produces a yellow stain upon the skin which, however, speedily evaporates. It fuses at 225°, and assumes the elastic form under the ordinary barometric pressure, at 350° Fahrenheit. In this aëriform state it is of a beautiful violet colour, and is 125 times heavier than hydrogen: 100 cubic inches of the vapour weighing 264.75 grains.

The spectrum of light passed through a dilute atmosphere of iodine, presents a series of equidistant lines, resembling those produced by bromine. A new and unexpected analogy is thus presented between two substances, which have always been remarkable as having many other properties in common. Both these elements also agree with chlorine, in acting most energetically upon the violet end of the spectrum, which, when the vapours are sufficiently dense, they entirely cut off.

Iodine has the property of forming an insoluble compound with starch, of a beautiful blue colour, which is so characteristic as to be used as a test of its presence in very minute quantities. A solution containing not more than one 450,000th of its weight, will become blue by the addition of a cold solution of this vegetable substance.

It is very soluble in ether and alcohol, and possesses bleaching powers, but not so great as those of chlorine and bromine.

The history of its combinations is almost a repetition of those of chlorine and bromine.

With the metals it forms binary compounds, which are called *iodides*, and are named in the same way as the oxides and chlorides.

Combination of Iodine and Hydrogen.

§ 581. When iodine is heated in hydrogen the volume of the gas is doubled, and a powerful, colourless, acid is produced, which is rapidly absorbed by water, and so readily acted upon by mercury, that it cannot long be preserved over that fluid. It may be procured in large quantities from the iodide of potassium or sodium, the latter of which is the salt which is contained in the ashes of sea-weeds, by the action of sulphuric acid.

The gas is colourless, has a very sour taste and pungent odour, and reddens blue vegetable colours without ultimately bleaching them. Mercury decomposes it, unites with the iodine, and leaves half the volume of hydrogen. Now:—

Cubic Inches.			Grains.
50	Hydrogen	weigh	1.06
50	Iodine vapour . . .	„	132.37
100	Hydriodic acid . .	„	133.43

which agrees with the weight by direct experiment. Hydriodic acid consists therefore of:—

Hydrogen	0.8	=	1	Equivalent.	1
Iodine	99.2	=	1	„	125
	100.0				126 (135).

Formula, (H + I).

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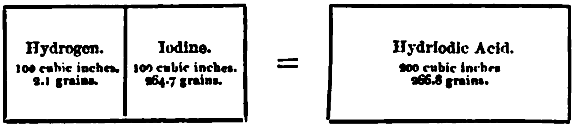
(135) The symbol of the hydriodic acid is similar to that of the hydro-bromic, and we have only to substitute the weight of 100 cubic inches of its vapour for that of bromine.



The concentrated solution of hydriodic acid in water fumes in the air, and has a density of 1.7. Mercury does not act upon it, although it decomposes the acid so readily in the gaseous state.

Chlorine decomposes it, forms muriatic acid with its hydrogen, and precipitates the iodine. It is also decomposed by exposure to the air; the oxygen of which abstracts the hydrogen, and sets the iodine free.

Compounds of Iodine and Oxygen.

§ 582. There are probably several compounds of iodine with oxygen, some of which require further examination; but the most permanent and best characterized is an acid of exactly similar constitution to that of the chloric and bromic acids. It cannot be obtained by the direct action of iodine upon oxygen, but may be formed by acting upon the hypo-chlorous acid, or the peroxide of chlorine, by iodine.

When the gas comes into contact with the solid, there is an immediate action; its colour changes to a bright orange, and a liquid is formed. By the application of a gentle heat, an orange-coloured volatile compound of chlorine and iodine is driven off, and a compound of iodine and oxygen remains. It is a white, semi-transparent solid, without smell, but possessing a strong astringent sour taste. It is very soluble in water, and its specific gravity is more than 2. Its aqueous solution first reddens, and then destroys blue vegetable colours.

Iodic acid is decomposed by heat, and the sole products are iodine and oxygen. It is composed of:—

Iodine 75.76 = 1 Equivalent. 125
Oxygen 24.24 = 5 Equivalents. 40
100.00 165

Formula, $(I+5\,O)$.

When mixed with charcoal, sugar, sulphur, and other combustibles, it detonates upon the application of heat, and all its salts deflagrate, like the chlorates, upon ignited charcoal.

Compounds of Iodine and Nitrogen.

§ 583. Iodine and nitrogen cannot be made to unite directly; but if iodine be kept for a short time in a solution of ammonia in water, the ammonia is decomposed; its hydrogen unites with one portion of the iodine, and its nitrogen with another. The latter compound, or *iodide of nitrogen*, is precipitated in the form of a deep brown powder. It evaporates spontaneously in the open air. Like the chloride of the same element it is highly explosive, either by heat or friction. It detonates violently almost as soon as it is dry, and slight pressure will produce the same effect even when moist.

It consists, according to its analysis, of:—

Iodine	96.4	=	3 Equivalents.	375
Nitrogen	3.6	=	1 Equivalent.	14
	100.0			389

Formula, $(3\,I+N)$.

§ 584. The advantages which the science of chemistry has derived from the discovery of the great law of definite and equivalent proportions cannot be better illustrated than by the history of the two last elementary substances compared with that of chlorine. They are of but recent discovery; and in a very few months after their announcement, they were placed upon the scale of equivalents with as much certainty as substances with which chemists had been acquainted from the first dawn of science. Chlorine had been the subject of doubt and controversy for a period of half a century before its nature was accurately determined; and just views of it were not, in fact, established till confirmed by the strong analogies which iodine and bromine present. Such is the importance of this law, which has now been established by a sufficient number of instances, that we feel confident that, when one or two careful experiments shall have been made upon any new substance, which may hereafter occur, in order to determine its equivalent number, all the proportions in which it can enter into combination with all other known bodies will at once be known. This is a degree of knowledge to which, without the law, the labours of a long life would be scarcely sufficient to attain: and it is possessed with a degree of clearness, which at once guides to experiment and corrects its results.

The substance, however, which must next occupy our attention, as being connected by strong resemblance of constitution to the three last, is calculated to repress any undue feeling of exultation at the present advanced position of our science, which reflexions like the preceding may be calculated to engender, for our present uncertain and hypothetical views concerning them have been deemed the reproach of chemistry.

Fluorine.

§ 585. Fluorine is the name of an elementary body which has not hitherto been obtained, at least in satisfactory quantities, in an insulated state. Its powers of combination are supposed to be so exalted and so extensive, that no body has been found capable of resisting its energetic action. The evidence of its existence is derived chiefly from analogy. It exists in nature as a component part of a few minerals, one of which only is found in any abundance. It is well known in mining districts by the name of *fluor spar.*

It is found crystallized ordinarily in cubes of various colours,—green, yellow, and purple; and there is a beautiful compact variety which occurs in Derbyshire, which is worked into splendid ornamental vases.

§ 586. If this mineral be reduced to powder, mixed with twice its weight of strong sulphuric acid, and subjected to distillation, a powerful and highly-corrosive liquid acid may be obtained. For this purpose a leaden or silver retort and receiver must be employed; and while a moderate heat is applied to the former, the latter must be kept cool by ice. The product must be preserved in leaden or silver bottles, upon which metals it has no action. It is extremely volatile, and not easily confined. In appearance it resembles oil of vitriol. Its specific gravity, when first prepared, is 1.06; but is increased, by the gradual addition of water, to 1.25. When dropped into water a hissing noise is produced, similar to that which is produced when red-hot iron is quenched in that liquid. It is necessary to be extremely cautious in experimenting with this substance, as its vapours are highly irritating, and when applied to the skin, even in small quantities, it disorganizes it so rapidly as to produce dangerous ulcers. In addition to the usual properties of a powerful acid, it possesses that of acting strongly upon glass, and corroding it deeply.

§ 587. When this acid, in a state of purity, is brought into contact with potassium, a violent detonation takes place; hydrogen gas is given off, and a solid white saline substance is formed. When lime is thrown into it, violent heat is generated, water is given off, and the same substance as fluor spar is produced. Hence, it has been concluded that the acid is composed of hydrogen united to an elementary substance resembling chlorine, bromine, &c., and which has been called *fluorine.* In the first experiment *fluoride of potassium* is formed and the hydrogen evolved, as in the analogous action of potassium upon dry muriatic acid gas: and in the second, *fluoride of calcium* (the metallic base of lime) is the result; the hydrogen of the acid, and the oxygen of the base, forming water.

§ 588. A strong argument in favour of this view of the constitution of hydro-fluoric acid is derived from the fact, that anhydrous sulphuric acid does not act upon fluor spar. There being no water present to furnish oxygen to the calcium, and hydrogen to the fluorine, the hydro-fluoric acid cannot be formed. It is probably constituted of:—

Hydrogen	5.26	= 1	Equivalent.	1
Fluorine	94.74	= 1	„	18
	100.00			19

Formula, $(F+H)$.

Sulphur.

§ 589. Our next non-metallic element, *sulphur,* (commonly known by the name of *brimstone,*) is one of the few elementary substances which occur in nature in their simple forms, and has been known from the earliest ages of the world. It is a mineral which is found in large quantities in the neighbourhood of volcanoes; and, as an article of commerce, is chiefly imported from the Mediterranean. It is also extracted for use from some of its natural compounds. It is commonly met with in two forms; that of a compact brittle solid, and a fine powder. It is of a light yellow colour, and when rubbed and melted emits a peculiar odour, but is tasteless. It is insoluble in water, and not very readily soluble in alcohol, but is taken up by spirits of turpentine. It has about double the weight of water, its specific gravity being 1.98. It is readily melted and volatilized; softens at 105°, and begins to evaporate at 170°. At 220° it becomes completely fluid; but possesses the peculiar property of solidifying at a higher degree, or at 350°, and of again melting by a reduction of temperature. This is a striking instance of that *di-morphism,* which we have before exemplified (§ 126) in the form of its crystals. At temperatures above 350° it again becomes perfectly liquid, and boils at 600°, forming an orange-coloured vapour, the density of which is about 6.6.

At mean pressure and temperature, 100 cubic inches of this vapour would weigh 206 grains, being 96 times heavier than hydrogen. It condenses in the form of a yellow powder, which is known by the name of *flowers of sulphur*.

In its affinities and modes of combination, it stands intermediate between oxygen, chlorine, and bromine, on the one hand, and hydrogen and carbon on the other, having strong analogies to both groups. Like the former, it enters into union with hydrogen and forms a hydro-acid; and combines with the metals, forming a series completely parallel with the oxides and chlorides, which are called *sulphurets;* and like the latter, it forms equally stable compounds with oxygen.

Compounds of Sulphur and Hydrogen.

§ 590. By repeatedly subliming sulphur in hydrogen, a combination between the two elements takes place without change of volume in the gas; and the product is properly called *hydrosulphuric acid*, but is generally known by the name of *sulphuretted hydrogen*. It may be produced in abundance, as we have already said (§ 531), by acting upon sulphuret of iron by dilute sulphuric acid. It is quickly absorbed by water; but may be collected over that liquid warmed, in glass bottles fitted with glass stoppers which must be inserted the moment they are filled with the gas.

It is colourless and transparent. Its smell is very fœtid and offensive, and its taste is slightly acid. It reddens the blue colour of litmus. It is highly poisonous, and a mixture of $\frac{1}{800}$th in the atmosphere has proved fatal to a dog which was forced to breathe it. It is inflammable, and, like hydrogen, burns either silently or with explosion, according to the circumstances of its mixture with oxygen. It instantly extinguishes all burning bodies immersed into it. The gas has been liquified by a pressure amounting to 17 atmospheres at 50°, and was colourless and very limpid. It exists in solution in some mineral waters. Water will take up about three times its bulk, and the solution possesses all the properties of the gas.

When one volume of gaseous hydro-sulphuric acid is detonated with half its volume of oxygen, the sulphur is precipitated and water formed: but when mixed with one volume and a half of oxygen, water is formed, and one volume of a gaseous compound of sulphur and oxygen.

The gas, therefore, consists of:—

Sulphur	94.1	=	1 Equivalent.	16
Hydrogen	5.9	=	1 „	1
	100.0			17

Formula, $(S+H)$.

Chlorine, bromine, and iodine, instantly decompose the hydro-sulphuric acid, combining with its hydrogen and precipitating the sulphur: and the best way of forming solution of hydriodic acid is to pass sulphuretted hydrogen through water holding iodine in suspension. The oxides of the different metals mostly decompose it, and water, and variously-coloured sulphurets of the metals are the products.

§ 591. A second combination of sulphur with hydrogen, of which the sulphur is double that of the last compound, may be formed by dropping a strong solution of *sulphuret of potassium*, or *calcium*, into dilute muriatic acid. A small quantity of sulphuretted hydrogen is given off, some sulphur is deposited, and an oil-like, adhesive, brown liquid falls to the bottom of the solution. It has a specific gravity of 1.769. Its smell and taste greatly resemble those of sulphuretted hydrogen. It burns with a blue flame, and has the property of combining with some bases in the manner of an acid. It has some properties which render it analogous to the peroxide of hydrogen (§ 490). It possesses like it considerable bleaching powers; its decomposition is effected by the mere contact of many substances, such as metals and metallic oxides. A strong effervescence from the escape of sulphuretted hydrogen is produced by peroxide of manganese, alkaline bases, and silica, and the oxide of silver is reduced with such energy as to become incandescent. The substances which occasion this decomposition at the same time undergo no change. It has been named *bi-sulphuretted hydrogen*.

Formula, $(2\,S+H)$.

Compounds of Sulphur and Oxygen.

§ 592. When sulphur is burned in dry oxygen gas, the latter undergoes no change of volume; but, at common temperatures and pressures, a colourless transparent gas is the product, which is distinguished from all other elastic fluids by a suffocating pungent odour well known as the smell of burning brimstone. It may be obtained in abundance, and in a state of great purity by the action of strong sulphuric acid upon mercury. The mixture may be put into a retort and heated, but the product of the operation must be collected over mercury. It is called *sulphurous acid gas.*

It extinguishes all burning bodies when immersed in it, and cannot itself be burned. It is instantly fatal to animal life. It assumes the liquid form under a pressure not exceeding that of two atmospheres, or at the degree of cold produced by a mixture of pounded ice and salt. It is then very limpid, and its refractive power is nearly equal to that of water. It first reddens blue vegetable colours, and afterwards destroys them. Its bleaching powers are considerable, and the vapour of burning sulphur is employed in whitening silk and straw-work.

One hundred cubic inches of oxygen just double their weight in combining in this way with sulphur, so that sulphurous acid is composed of:—

Sulphur	50	=	1 Equivalent.	16
Oxygen	50	=	2 Equivalents.	16
	100.			32

Water at 60° dissolves about thirty-three times its bulk of this gas; and the solution possesses its peculiar odour and taste, which is astringent.

Formula, $(S+2\ O)$.

§ 593. A mixture of sulphurous acid and oxygen gases may be kept for any length of time without showing any disposition to combine, provided they be quite free from moisture. But if water be present, the sulphurous acid will gradually unite to a further proportion of oxygen; and the compound, which is *sulphuric acid*, will be taken up by the water. A solution of sulphurous acid also undergoes the same change by exposure to the air.

By boiling sulphur in nitric acid it may also be oxigenated to the utmost, and sulphuric acid formed. It is an article of very considerable importance, and largely employed in the arts.

By distilling at a high heat the salt which is commonly known by the name of *green vitriol*, which is a compound of sulphuric acid and protoxide of iron, the water of crystallization is first driven off, and a dense, oily, colourless liquid may be afterwards collected; which emits white vapours on exposure to the air. If this liquid be again distilled at a lower temperature, into a receiver kept cool by ice, a transparent colourless vapour will pass over, and concrete into a white solid, of the texture of asbestus or flocks of silk. It is tough and elastic, liquifies at a temperature of about 66° Fahrenheit, and boils between 110° and 120°. It has a strong attraction for water, and takes it from the atmosphere. This solid body is pure *anhydrous* sulphuric acid, and the residue in the retort will be common oil of vitriol, or *aqueo*-sulphuric acid. When the former is passed through a red-hot porcelain tube, it is resolved into one volume of oxygen gas and two of sulphurous acid.

§ 594. The difference between the forces of chemical affinity and mere adhesion cannot be more strikingly exemplified, perhaps, than by the relations of this acid to water. The combination of the first equivalents so completely alters their nature as that two volatile substances become comparatively fixed; but any further addition of water only produces the common effects of mixture and dilution.

§ 595. The aqueo-sulphuric acid is also extensively manufactured by burning a mixture of about 8 parts of sulphur and 1 of nitre in a properly constructed furnace, with a strong draft of air, and receiving the products of the combustion into large leaden chambers, the bottoms of which are covered with water. The water becomes gradually acidulated, and the concentrated acid is obtained by subsequent evaporation of the solution. The process is extremely interesting.

The sulphur by burning in the atmospheric air forms sulphurous acid, and the nitre gives rise to the formation of deutoxide of nitrogen, which, with the oxygen of another portion of the air, produces nitrous acid gas. Now when those two acids are perfectly dry, they mix without any further action upon each other; but with a small quantity of moisture they form a colourless, transparent, crystalline compound which is instantly decomposed by the further addition of water. But the products of the decomposition are sulphuric acid, which remains in solution, and deutoxide of nitrogen, which rises in the gaseous state. One equivalent of nitrous acid thus transfers two equivalents of oxygen to two equivalents of sulphurous acid, and converts them into two equivalents of sulphuric acid. The deutoxide by the action of the air again affords nitrous acid, which plays the same part as before with fresh portions of the burning sulphur (136).

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(136) The compositions and decompositions of this process present a beautiful illustration of equivalent proportions, and of the play of

§ 596. The *aqueo-sulphuric acid*, or oil of vitriol, is a colourless oily liquid, of a specific gravity, when most concentrated, of 1.85, at which density it contains about 81 per cent. of real acid. It boils at 620°, and freezes at 15°; but if diluted with water, so as to have a specific gravity of 1.78, it crystallizes at 32°, and remains solid even to the temperature of 45°. It rapidly attracts moisture from the air. It is acrid, corrosive, and intensely sour, and its affinities are amongst the most powerful with which chemists are acquainted. It decomposes animal and vegetable substances rapidly from its strong attraction for water, the elements of which it abstracts from organic compounds, and disengages their carbon. The constitution of sulphuric acid is as follows:—

Sulphur	40	=	1 Equivalent.	16
Oxygen	60	=	3 Equivalents.	24
	100			40

Formula, $(S+3O)$.

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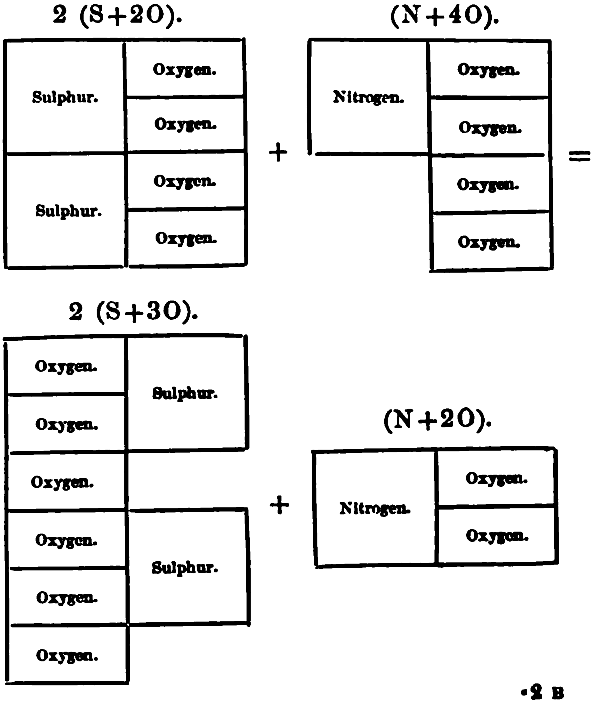
elective affinity. The following diagram represents the constitution of the several bodies concerned in the action:—



The composition of the aqueous-acid, specific gravity, 1.85: is,—

Anhydrous sulphuric acid	81.63	= 1 Equivalent.	40
Water	18.37	= 1 „	9
	100.00		49

Formula, $(S+3O)+\overline{H+O}$.

The equivalent combining number of sulphuric acid is, therefore, 40; which exactly agrees with the constitution of its salts.

§ 597. Besides these two principal compounds of sulphur and oxygen, there are two other acids; the first of which, in equivalent composition, is below the sulphurous, and is called the *hypo-sulphurous;* and the second is between the sulphurous and the sulphuric, and is called the *hypo-sulphuric acid.*

§ 598. When iron or zinc filings are digested in a solution of sulphurous acid, they are taken up without any effervescence, and peculiar, crystallizable, salts are produced, which, when treated with any of the stronger acids, evolve sulphurous acid, and deposit sulphur. Now, as no acid can dissolve a metal without previously converting it into an oxide, by the decomposition of water or by its own decomposition, it is clear that in this process the metal must take oxygen from the sulphurous acid, and the base so formed combines with an acid in which the oxygen must exist in less proportion. The hypo-sulphurous acid cannot, however, be exhibited in the separate form; for at the moment of quitting the base with which it was united, it is resolved into sulphurous acid and sulphur. In this property it resembles the hypo-nitrous acid. The same series of salts may be formed by digesting sulphur in solutions of any of the sulphites, or by directing a current of sulphurous acid into solutions of the hydro-sulphurets. Although the simple equivalent proportions of this acid are 1 of sulphur and 1 of oxygen, it appears from the analysis of its salts that its number is double the amount thus indicated, and that it must be considered as a compound of:—

Sulphur	66.67	= 2 Equivalents.	32
Oxygen	33.33	= 2 „	16
	100.00		48

Formula, $(2S+2O)$.

§ 599. The hypo-sulphites are distinguished as a class by dissolving fresh-precipitated chloride of silver, and forming with it a compound of an intensely sweet taste.

§ 600. By passing sulphurous acid into water, in which finely-divided per-oxide of manganese is suspended by agitation, the peroxide yields part of its oxygen to the acid, and converts one portion into sulphuric acid and another into the *hypo-sulphuric*. To the liquid, after it has been filtered, a solution of pure baryta is added in slight excess, which precipitates the protoxide of manganese which was combined with the two acids, and forms an insoluble sulphate of baryta with the sulphuric, and a soluble hypo-sulphate with the hypo-sulphuric acid. The hypo-sulphate is then again decomposed by a quantity of sulphuric acid exactly sufficient to precipitate the baryta, and the hypo-sulphuric acid remains in solution. It may be concentrated by exposure to the action of sulphuric acid under the exhausted receiver of the air-pump, to the specific gravity of 1.347; but if an attempt be made to condense it further, it is decomposed; sulphurous acid escapes, and sulphuric acid is left in solution. This change is still more readily effected by heat. The composition of the hypo-sulphuric acid is:—

Sulphur	44.44	2 Equivalents.	32
Oxygen	55.56	5 „	40
	100.00		72

And 72 is its combining number.

Formula, $(2\,S + 5\,O)$.

Compound of Sulphur and Carbon.

§ 601. By bringing the vapour of sulphur in contact with charcoal at a red heat, and collecting the products in a cooled receiver, a *bi-sulphuret of carbon* may be obtained in the form of a colourless, transparent, liquid, of the specific gravity of 1.272. Its taste is acrid, pungent, and somewhat aromatic; its odour, fœtid and nauseous in the highest degree. It is very volatile, and boils at common atmospheric pressure, at a temperature not exceeding 110° Fahrenheit. It has never been congealed by the lowest artificial temperature. It is highly inflammable, and it burns with a blue flame, emitting copious fumes of sulphurous acid. No moisture is deposited upon cold surfaces during its combustion, proving that hydrogen does not enter into its composition. It mixes readily with alcohol and ether, but not with water: the latter precipitates it from either of the former mixtures. It is composed, according to the results of its analysis, of:—

Sulphur	84.21	= 2 Equivalents.	32
Carbon	15.79	= 1 Equivalent.	6
	100.00		38

Formula, $(2S + C)$.

Compound of Sulphur and Chlorine.

§ 602. Sulphur may be united directly with chlorine by passing a current of the gas over it, in a state of minute division and at a gentle heat. Ten grains of the flowers of sulphur will thus take up 30 cubic inches of gas, which is nearly in the proportion of single equivalents of the two bodies. *Chloride of sulphur* is a volatile liquid, of reddish colour by reflected light, but yellowish green by transmitted light. It emits fumes which affect the eyes, rises in vapour at a temperature below 200°, and boils at 280°. Its specific gravity is 1.6. It does not redden the colour of perfectly dry litmus, but when agitated with water, a great disengagement of heat takes place, sulphur is precipitated, and the liquid is found to consist of a mixture of muriatic, sulphurous, and sulphuric acids. It acts strongly upon mercury; the surface of the metal is instantly tarnished, great heat is evolved, and a gray powder is the result, which is a mixture of proto-chloride of mercury and sulphur.

Formula, $(S + C^{l})$.

Selenium.

§ 603. A new and rare elementary substance has very recently been detected in the refuse of an oil-of-vitriol manufactory in Sweden, which in all its compositions runs as parallel with sulphur as iodine and bromine do with chlorine. It owes its origin to the iron pyrites, (or native compound of iron and sulphur,) which are employed in the works, and which contain a mixture, in very minute proportions, of a similar compound of *selenium* and iron.

Selenium at common temperatures is a brittle solid, of a brown colour and metallic lustre; it has neither taste nor odour. When pounded the particles stick together, and in powder it has a deep red colour. It melts at a few degrees above the boiling-point of water, and when warm is very ductile, and may be drawn into threads, which are red by transmitted, but gray by reflected light. It boils at a temperature of about 600° Fahrenheit, and condenses either in opaque, metallic-looking, drops, or, when large receivers are used, in flowers of the colour of cinnabar. Its vapour has a deep-yellow colour. It is insoluble in water, and undergoes no change by mere exposure to air. Its specific gravity is 4.3. It is a non-conductor of electricity, and a bad conductor of heat. When heated before the blow-pipe it tinges the flame of a light-blue colour, and exhales an odour of decayed horse-radish.

Combinations of Selenium and Oxygen.

§ 604. The mode of its extraction from the refuse which we have mentioned will make us acquainted with one of its combinations. By treating the mixture, which contains much sulphur, with nitric acid, both the sulphur and the selenium are acidified; sulphurous acid and *selenious* acid are formed. The former reacts upon the latter, takes its oxygen from it, and the selenium sublimes.

When selenium alone is subjected to the action of nitric acid, and the solution evaporated so as to expel the excess of that acid, a white saline matter remains which may be sublimed by raising the temperature; the colour of the vapour closely resembling that of chlorine. The *selenious acid* crystallizes in needles in the colder part of the apparatus. Selenious acid has a sour and slightly burning taste, and is very soluble both in water and alcohol. It is readily decomposed by all substances which have a strong attraction for oxygen, and the selenium may be precipitated from its solution by metallic zinc and iron. It may be considered as a compound of:—

Selenium	71.43	=	1 Equivalent.	40
Oxygen	28.57	=	2 Equivalents.	16
	100.00			56

Formula, $(S^{m} + 2\,O)$.

Which makes its equivalent 56, in which proportion it enters into combination with the different bases.

§ 605. As the selenious acid exactly resembles the sulphurous in constitution, so the *selenic acid* is exactly analogous to the sulphuric. The process for obtaining it is circuitous. Selenious acid must be neutralized with soda, and the resulting salt fused with about its own weight of nitrate of potassa, or soda, by projecting it in successive portions into a red-hot crucible. The selenious acid thus takes another equivalent of oxygen, and a combination of selenic acid and soda is the result. The fused mass is then acted upon by a hot mixture of nitric acid and water, and the solution made to boil briskly; when anhydrous seleniate of soda is deposited. The hot liquid decanted from the salt deposits crystals of the excess of nitrate upon cooling. On renewing the ebullition fresh portions of the seleniate are procured; and the process is renewed till the whole is separated. This process is founded upon the fact that seleniate of soda, like the sulphate of the same base, is more soluble in water of about 90°, than at higher or lower temperatures. The nitrite of the base which is formed by the decomposition of the nitrate is purposely reconverted into a nitrate by the addition of the nitric acid.

§ 606. To procure the acid in a free state, a solution of the seleniate is decomposed by nitrate of lead. The seleniate of lead which is formed is perfectly insoluble, like the sulphate, and after being well washed, is suspended in water, and exposed to a current of sulphuretted hydrogen which precipitates all the lead but does not decompose the selenic acid. The excess of sulphuretted hydrogen is driven off by heat, and the filtered liquid consists of a dilute solution of selenic acid in water.

When concentrated, selenic acid is a colourless liquid, which may be heated to 536° without decomposition; but above that temperature, it is resolved into selenious acid and oxygen. Its specific gravity, at the highest, is about 2.6. The affinity of selenic acid for bases is little inferior to that of the sulphuric acid. It consists of:—

Selenium	62.5	=	1 Equivalent.	40
Oxygen	37.5	=	3 Equivalents.	24
	100.0			64

Formula, $(S^{m} + 3\,O)$.

Compound of Selenium and Hydrogen.

§ 607. To establish completely the remarkable analogy between selenium and sulphur, we shall describe one more of the compounds of this rare substance; namely, that which it forms with hydrogen. It may be obtained by acting upon *selenuret of potassium* (formed by fusing together potassium and selenium) with dilute muriatic acid. A gas is thus formed, which may be collected in the same way as sulphuretted hydrogen.

In odour, these two gases a good deal resemble each other. It may be called *hydro-selenic acid*, or *selenuretted hydrogen*. It is absorbed by water with which it forms a colourless solution. It reddens litmus paper, and stains the epidermis brown. It is gradually, but completely, decomposed by contact with the air, and the selenium deposited in a red precipitate. It throws down all metallic solutions in the form of selenurets. This gas produces violent effects upon the organs of respiration, and a sharp and painful sensation in the nose which is followed by a temporary loss of the sense of smelling. According to its analysis it is composed of:—

Selenium	97.56	=	1 Equivalent.	40
Hydrogen	2.44	=	„	1
	100.00			41

Formula, $(S^m + H)$.

Phosphorus.

§ 608. The next element which we shall describe is a very remarkable substance, and has never been found in nature in its simple form: but in combination with oxygen and lime, it is a product chiefly of the animal kingdom. It is a combustible to which we have already frequently referred by the name of *phosphorus*. It differs not more from the other combustibles which we have hitherto examined in its peculiar properties, than in its modes of combination.

It may be prepared by calcining bones in an open fire, to burn off and dissipate all the volatile ingredients, reducing their earthy residue to a fine powder, and digesting them for two or three days in half their weight of sulphuric acid, adding as much water as may give the mixture the consistence of a thin paste. At the expiration of the time, twice the bulk of boiling water must be stirred up with it, and the liquid separated by filtration. In this operation the sulphuric acid displaces *phosphoric acid* from the lime with which it is combined in the bone earth, and it may be concentrated by evaporation to the consistence of a thick syrup. It must then be mixed with one-fourth its weight of charcoal in powder, and strongly heated in an earthen-ware retort, the beak of which must be plunged under water. The heat must be very slowly raised till it becomes very intense. A large quantity of gas will escape during the process, and spontaneously inflame upon passing through the water into the air; and the phosphorus will distil over in drops and congeal in the water. In this process the phosphoric acid is deoxydated by the charcoal, which at a high temperature has a stronger affinity for the oxygen than the phosphorus (137).

§ 609. As thus obtained it is a soft solid of a flesh-red colour; but when purified by fusion under a warm solution of ammonia, and a second time under alcohol, it is perfectly colourless and transparent. It may be obtained in octohedral crystals from its solution in naphtha, or sulphuret of phosphorus. Its specific gravity is 1.77. It is highly inflammable and takes fire by slight friction, and it is necessary to preserve it under water in well-closed bottles. It may easily be cut with a knife. When air is carefully excluded, or under water, it melts at about 105°, and boils at 550°: 100 cubic inches of its vapour weigh 135 grains. It is tasteless and insoluble in water, but proves highly poisonous when taken into the stomach.

§ 610. In the atmosphere, phosphorus emits a light smoke and peculiar smell, not unlike that of garlic: the smoke shines in the dark with a pale-greenish and very beautiful light. This is owing to a slow combustion, or combination with oxygen, and if a stick of phosphorus be confined under a jar full of common air over

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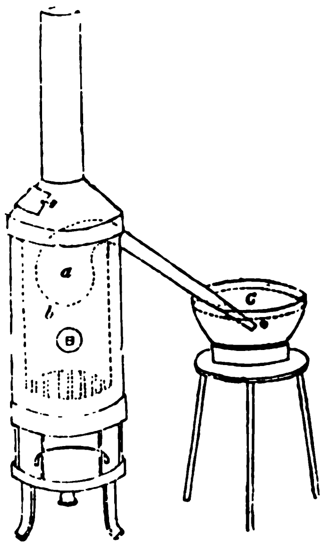


(137) The apparatus for the preparation of phosphorus is here delineated. The mixed phosphorous acid and charcoal is placed in retort, *a*, which is properly adjusted in the furnace, *b*. The neck of the retort dips under the water in the basin, *c*.

water, the whole of the oxygen will gradually be absorbed and the nitrogen remain, and then its light will be extinguished.

It is remarkable that phosphorus does not shine in perfectly pure oxygen till heated to 80°, near which point it bursts into flame; and no absorption takes place under this temperature: but if the elasticity of the gas be decreased to about one-eighth or one-tenth of that of the usual elasticity of the air, the slow combustion with the evolution of the glow will take place. If the density of the oxygen be reduced to the same amount by mixture with hydrogen, nitrogen, or carbonic acid, the same phenomena will be produced. Some caution should be used in exposing this highly inflammable substance to the air, as the heat which is evolved during this slow combustion sometimes accumulates to a sufficient degree to cause the whole to burst into flame. Pieces of phosphorus placed upon cotton or charcoal, or other bad conductors of heat, will almost always accumulate heat enough for this purpose.

§ 611. Phosphorus combines with many of the metals, forming with them *metallic phosphurets*. They may be obtained by heating the two substances together; and sometimes by passing a compound of phosphorus and hydrogen into solutions of the oxides. Phosphuretted hydrogen, however, by no means acts with the same certainty as the different hydro-acids which we have examined; in most cases the metal is merely reduced. Phosphorus alone will, indeed, reduce those metals which have but a feeble attraction for oxygen, and a stick of phosphorus introduced into solutions of gold, silver, or platinum, will become coated by the respective metals.

It is not known that the phosphurets enter into secondary combination, and they do not possess much interest.

Compounds of Phosphorus and Oxygen.

§ 612. The product of the slow combustion of phosphorus which has just been described, is an acid liquid; and a mixture of *phosphorous and phosphoric acids*. No good process is, however, known, by which they may be separated from this liquid.

Phosphorous acid, in combination with water, may be obtained by passing a current of chlorine through phosphorus fused under hot water; a chloride of phosphorus is thus formed, which is immediately resolved into muriatic acid and phosphorous acid by the decomposition of the water; the former may be expelled by evaporation, and the latter will remain. It is a crystallizable compound, of a sour taste and very soluble in water. By heat it is resolved into a compound of phosphorus and hydrogen, which escapes, and phosphoric acid which is fixed. It may be obtained in the anhydrous state in small quantities, by burning phosphorus in a long tube with a very limited access of air. In this case it sublimes in the form of a white volatile powder, which rapidly absorbs moisture from the air. It is composed of:—

Phosphorus	57.14	=	1 Equivalent.	16
Oxygen .	42.86	=	1½ Equivalents.	12
	100.00			28

Formula, $(2\,P+3\,O)$.

And 28 constitutes the equivalent in which it enters into secondary combination with the bases, and constitutes the class of salts which are denominated *phosphites*.

§ 613. An acid of inferior degree of oxygenization may be formed by acting upon water by *phosphuret of barium*. Hydrogen in combination with phosphorus makes its escape, and a solution of the *hypo-phosphorous acid* in combination with baryta, remains, from which the base may be precipitated by the cautious addition of sulphuric acid. When the clear filtered liquor has been concentrated by evaporation, it contitutes a sour viscid liquid which is incapable of crystallization, and rapidly attracts oxygen. It consists of:—

Phosphorus	80	=	2 Equivalents.	32
Oxygen .	20	=	1 Equivalent.	8
	100			40

Formula, $(2\,P+O)$.

§ 614. When phosphorus is burned in the open air, it generally leaves a red insoluble residue, which is a compound of phosphorus with still less oxygen than the preceding, and is an *oxide of phosphorus*. It may be formed in greater abundance by directing a small stream of oxygen upon phosphorus, kept melted under boiling water. The acids which are formed at the same time are retained in solution, while the red oxide floats in the liquid. When dried, it must be exposed to heat in a retort, to drive off any uncombined phosphorus, and afterwards washed and dried. It possesses neither odour nor taste. It is heavier than water, and insoluble in that liquid and in alcohol, ether and oils. It does not inflame till exposed to a temperature approaching to redness, when it burns into phosphoric acid. The results of its analysis prove it to be a compound of:—

Phosphorus	85.78	=	3 Equivalents.	48
Oxygen .	14.22	=	1 Equivalent.	8
	100.00			56

Formula, $(3\,P+O)$.

§ 615. *Phosphoric acid*, or phosphorus at its maximum degree of oxidation, may be obtained from the impure acid, the extraction of which from bones has been already described (§ 608), by boiling it with carbonate of ammonia in excess. The liquid after filtration is to be evaporated to dryness, and then ignited in a platinum crucible; by which ammonia, and other volatile matters are driven off.

It may also be formed by the action of nitric acid on phosphorus. For this purpose, small fragments must be very cautiously dropped into the acid, gently heated in a retort. The action is very violent, and a large quantity of deutoxide of nitrogen is disengaged. A small quantity of ammonia is at the same time produced by the decomposition of water, which may be expelled by evaporating the liquid to the consistence of a syrup, and afterwards exposing it in a platinum crucible to a dull red heat.

In both these processes, the acid is obtained in combination with water, which it retains even at a red heat, and with which at a high temperature it may be sublimed. This aqueous acid sometimes goes by the name of *glacial phosphoric acid.*

§ 616. The white matter which is formed during the inflammation of phosphorus in oxygen gas, or common air, and which falls like flakes of snow, is pure anhydrous phosphoric acid. Its constitution according to its most accurate analysis, is:—

Phosphorus	44.44	=	1 Equivalent.	16
Oxygen .	55.56	=	2½ Equivalents.	20
	100.00			36

Formula, $(2\,P+5\,O)$.

And the glacial phosphoric acid consists of:—

Phosphoric acid	80	=	1 Equivalent.	36
Water . . .	20	=	1 „	20
	100			56

Formula, $(2\,P+5\,O)+\overline{H+O}$.

It very speedily deliquesces in the air into an intensely sour liquid of the specific gravity 2. It does not corrode animal and vegetable substances. The solution is not volatile, nor is it capable of being decomposed by heat alone. It emits no odour when heated.

§ 617. This acid undergoes certain changes in the ultimate arrangement of its constituent particles, without alteration of their equivalent proportions, by particular treatment with heat and with water. These modifications are chiefly distinguished in the composition of its salts.

When phosphoric acid, or any of its salts, have been exposed to a heat of 415°, it is recognised by precipitating nitrate of silver of a white colour; and the acid in this state has been distinguished by the name of the *pyro-phosphoric acid.* When it has not been exposed to such a temperature, or when after having been so exposed it, or its salts, is dissolved in water and boiled, it produces a yellow precipitate with nitrate of silver, and then goes by the name of phosphoric acid.

§ 618. The acid, again, which is obtained by heating to redness a concentrated solution of either phosphoric or pyro-phosphoric acids is in a third state, and called *meta-phosphoric acid.* It is distinguished by precipitating oxides of silver in gelatinous flakes of a gray colour. The phosphoric and the pyro-phosphoric acids, on the one hand, are both converted into meta-phosphoric by exposure to a red heat, and on the other, the aqueous solutions of the meta-phosphoric and the pyro-phosphoric acids readily pass into phosphoric, by boiling their aqueous solutions.

§ 619. The acid in these its three states, is distinguished by a tendency to unite with bases in different proportions, and when not in saline combination is supposed to be constituted of anhydrous acid with corresponding equivalents of water. Thus:—

$$\begin{array}{rcl}
(P+2\tfrac{1}{2}\,O) & = & \text{Anhydrous phosphoric acid.} \\
(P+2\tfrac{1}{2}\,O)+1\tfrac{1}{2}\,(H+O) & = & \text{Hydro-phosphoric acid.} \\
(P+2\tfrac{1}{2}\,O)+\phantom{1\tfrac{1}{2}}\,(H+O) & = & \text{Pyro-phosphoric acid.} \\
2\,(P+2\tfrac{1}{2}\,O)+\phantom{1\tfrac{1}{2}}\,(H+O) & = & \text{Meta-phosphoric acid.}
\end{array}$$

If we view the water in these compounds in the light of a base, then when any of them is treated with a stronger base, the whole, or a part, of the water is displaced, but in such a way that the total amount of base in combination with the anhydrous acid, may be regarded as remaining the same.

Thus, the series of multiples of water in the varieties of the phosphoric acid are, 1½, 1, ½, while the series of multiples of oxygen which constitutes the acids of phosphorus, are ½, 1½, 2½. To avoid the appearance of the half equivalent, the equivalent of phosphorus may be doubled, and the same series of the equivalents of oxygen becomes 1, 3, 5; but the compound equivalents, hence resulting, do not agree with the constitution of the salts in secondary combination. The same series is maintained in its other primary combinations, where more than one is known with the same element.

Compounds of Phosphorus and Hydrogen.

§ 620. The examination of the compounds of phosphorus and hydrogen, and, it may indeed be said, of all the compounds of phosphorus, is attended with considerable difficulty. We have already stated that when aqueo-phosphorous acid is heated, a gaseous compound of phosphorus and hydrogen is given off. It is transparent and colourless, and of an excessively offensive odour and bitter taste. Water absorbs one-eighth of its volume; but it is much more freely taken up by solutions of sulphate of copper and chloride of calcium. It has no acid reaction upon vegetable colours; but like sulphuretted hydrogen decomposes some metallic salts with the formation of phosphurets of the metals. It is very poisonous, and will not support combustion. When pure, it may be mixed with common air, or oxygen, without danger, but the mixture explodes with the electric spark, or at a temperature of 300°. Diminishing the pressure will also cause it to explode, as by raising the jar upon the mercurial bath so that the mercury in the interior may be lifted about an inch or two.

§ 621. *Phosphuretted hydrogen* is also formed by the decomposition of water on boiling phosphorus in a strong solution of potassa in a small retort; and again by the action of *phosphuret of calcium* upon water. The product of these processes is, however, distinguished by being spontaneously inflammable in common air, or oxygen; a property which the gas loses by being kept over water. Each bubble, as it reaches the surface of the water, bursts into flame, and forms a ring of white smoke composed of phosphoric acid, which is very beautiful in a still atmosphere. The two gases are essentially the same in composition; but in the latter state it is probable that it contains a very small proportion of another compound of hydrogen and phosphorus, which is the spontaneously inflammable ingredient, and causes the combustion of the whole. Phosphuretted hydrogen is probably composed of three volumes of hydrogen, united to one-fourth of a volume of phosphorus in vapour, condensed into two. According to its analysis it contains by weight:—

Phosphorus	91.43	= 2 Equivalents.	32
Hydrogen .	8.57	= 3 „	3
	100.00		35

Formula, $(2\,P+3\,H)$.

§ 622. Possessing neither acid nor alkaline properties very decidedly, phosphuretted hydrogen bears some analogy on one hand to the hydro-acids, as we have stated with regard to its action upon the solution of metallic oxides (§ 611), and on the other hand to ammonia. It unites with hydro-bromic acid, hydro-iodic acids, and forms with them definite compounds which crystallize in cubes.

Combinations of Phosphorus and Chlorine.

§ 623. By passing the vapour of phosphorus over bi-chloride of mercury heated in a glass tube, a volatile liquid is obtained, which is a *sesqui-chloride of phosphorus.* It is transparent and colourless; of the specific gravity of 1.45. It does not affect the colour of dry litmus, but the fumes which it gives off in abundance are acid, owing to contact with the moisture of the air. It acts energetically upon water; the hydrogen combining with the chlorine to constitute muriatic acid and the oxygen with the phosphorus, by which phosphorous acid is generated. It consists of:—

Phosphorus	22.5	= 1 Equivalent.	16
Chlorine .	77.5	= 1½ Equivalents.	54
	100.0		70

Formula, $(2\,P+3\,C^{l})$.

§ 624. When phosphorus is introduced into chlorine, it spontaneously inflames, and burns with a pale flame, and another compound is formed, which is a *per-chloride of phosphorus.* The product is a white solid which condenses upon the cool parts of the containing vessel. It is volatile at a temperature below 212°, but may be fused under pressure, and crystallizes on cooling. It acts with violence upon water, forming with its elements muriatic and phosphoric acids. One grain of phosphorus combines in this way with six of chlorine, which is in the proportion of 16 : 90. Or :—

Phosphorus	15.1	= 1 Equivalent.	16
Chlorine .	84.9	= 2½ Equivalents.	90
	100.0		106

Formula, $(2P+5Cl)$.

Compound of Phosphorus and Nitrogen.

§ 625. When either of the chlorides of phosphorus are made to act upon dry ammonia, a white solid mass is obtained which gives off muriatic acid, and excess of ammonia, at a strong red heat; and leaves behind, out of the contact of air, a white substance, which is a compound of phosphorus and nitrogen. When preserved from the agency of air and moisture, it is perfectly fixed and infusible at a red heat, and it is remarkably indifferent to the strongest reagents. Concentrated nitric acid very slowly converts a portion of it into phosphoric acid, and concentrated oil of vitriol as slowly effects the same change with the evolution of sulphurous acid. When fused with caustic potassa, ammonia is given off, and phosphate of potassa remains. Dry hydrogen at a red heat decomposes it with the formation of ammonia, and phosphorus distils off. There is no trace of the formation of water during the action. *Phosphuret of nitrogen* consists of :—

Phosphorus	53.2	= 1 Equivalent.	16
Nitrogen .	46.8	= 1 „	14
	100.0		30

Formula, $(P+N)$.

This substance is a remarkable instance of the production of a fixed substance by the combination of highly volatile principles, and presents a curious contrast to the detonating and easily decomposable compounds of chlorine and iodine with the same element.

Silicon.

§ 626. To complete this general view of the non-metallic elements, it only remains that we describe the properties, and a few of the combinations, of *silicon* and *boron;* two undecompounded substances, which differ very materially from all the preceding, but are connected together by the strongest resemblances. Like carbon, they are known only in the solid state, and are perfectly fixed at the strongest heat; the only effect of which upon them, is to render them harder.

§ 627. Although *silicon* in combination with oxygen is one of the most abundant substances in nature, so much so as to entitle it to be considered the basis of the mineral kingdom, as charcoal is of the vegetable and animal, its insulation is only of very recent date.

By heating a mixture of fluor-spar and silica, or flint, with strong sulphuric acid, at a moderate heat, an acid gas is obtained, which, by being passed into a solution of potassa, combines with it, and forms a salt, which must be separated by evaporation, and afterwards heated nearly to redness. By mixing this salt with about eight times its weight of potassium, and heating it in a green glass or iron tube, a decomposition takes place, accompanied by a feeble detonation before the mixture becomes red-hot. When the mass has become cold, all the soluble parts may be removed by washing, and silicon will remain. It will be in the form of a solid, in a disintegrated state, of a dark-brown colour, and without metallic lustre. It does not conduct electricity, and, when first prepared, is combustible both in common air and in oxygen gas. It is not acted upon by the sulphuric or nitric acids, even when assisted by heat. When it has been exposed to a high temperature it becomes very hard, and will not burn even in oxygen gas.

Combination of Silicon und Oxygen.

§ 628. To oxidate silicon completely, it may be mixed with dry carbonate of potassa, and heated to redness; it then burns vividly at the expense of the carbonic acid; carbonic oxide is disengaged, and some carbon deposited. In this process silicon combines with its own weight of oxygen, and forms *silica*, or pure *flint*, which, upon the supposition of its being a protoxide, is composed of:—

Silicon	50	= 1	Equivalent.	8
Oxygen	50	= 1	„	8
	100			16

Formula, $(S^{n}+O)$;

and the equivalent of silicon is the same as that of oxygen.

§ 629. Silica is found in a state of purity in the form of rock-crystal, which is perfectly colourless and transparent. It may also be obtained by calcining common flints, quenching them in water, and then reducing them to powder. In this state they must be mixed with four or five times their weight of carbonate of potassa, and fused in a crucible at a strong red heat. The compound may be dissolved, when cold, in water, and the alkaline solution dropped gradually into dilute muriatic acid. The muriatic acid combines with the potassa, and the silica is separated in the form of a white translucent jelly. This is, in fact, a hydrate of silica. If the whole be evaporated to dryness, and the saline matter be washed off from the fused mass, pure silica will remain. It is a perfectly white, tasteless, powder, which feels harsh between the fingers. Its specific gravity is 2.6. It is insoluble in water and in every acid, except the hydro-fluoric. When first precipitated, it is taken up by solutions of potassa and soda, but not by the volatile alkali. It is perfectly infusible by all ordinary means, but is said to have been melted in the oxy-hydrogen blow-pipe. It ranks with the oxy-acids, from its combining with the fixed alkalies.

Compound of Silicon and Chlorine.

§ 630. When silicon is heated in a current of chlorine, it ignites and forms a compound, which is rapidly volatilized. The product of the combustion condenses into a liquid, which is colourless when pure, but is generally yellow from a portion of chlorine mixed with it. It may also be produced by the joint action of chlorine and carbon upon silica; and the process affords a good example of the efficacy of two concurring affinities, when neither singly would be efficient. It consists in mixing equal parts of hydrated silicic acid and starch into a paste with oil, and heating the mass in a covered crucible, so as to char the vegetable matters. In this way an intimate mixture of silica and carbon is obtained, which is placed in fragments in a porcelain tube and heated to redness, while a current of dry chlorine is passed over it. The oxygen of the silica unites with the carbon, and forms carbonic oxide; and the silicon and the chlorine at the same moment combine. Neither carbon nor chlorine, singly, have the slightest action upon silica. The volatile product is agitated with a little mercury to free it from mixed chlorine, and is then very pure.

Chloride of silicon has a suffocating odour, not unlike that of cyanogen, and when thrown into water is converted into muriatic acid and silica. It consists of:—

Silicon	18.3	= 1	Equivalent	8
Chlorine	81.7	= 1	„	36
	100.0			44

Formula, $(S^{n}+C^{l})$.

Compound of Silicon and Fluorine.

§ 631. We have already stated that hydro-fluoric acid acts very energetically upon glass: or, as we may now add, upon pure silica. The product of the action is a gas, which may easily be obtained by pouring upon powdered fluor-spar, mixed with half its weight of fine sand or glass, an equal weight of strong sulphuric acid. It may be collected in glass jars over mercury. It is colourless, and possesses a penetrating odour and sour taste. It extinguishes all burning bodies when immersed in it, and produces white fumes in the air from its high attraction for moisture. 100 cubic inches weigh about 112 grains.

Water absorbs 263 times its bulk of the gas, and the solution may be kept in glass vessels. About 17 per cent. of silica is precipitated during the solution, owing to the decomposition of water, the oxygen of which unites with the silicon, and the hydrogen with the fluorine, which forms hydro-fluoric acid, and which remains in solution. The gas condenses twice its volume of ammonia, and forms with it a dry, saline compound. It also combines with other bases.

The gas is most probably a binary compound of silicon and fluorine, and its proper name would, therefore, be *fluoride of silicon*. It is sometimes called fluo-silicic acid. It is composed of:—

Silicon	30.8	= 1	Equivalent	8
Fluorine	69.2	= 1	„	18
	100.0			26

Formula, $(S^{n}+F)$.

Boron.

§ 632. When two parts of potassium are mixed with one of *boracic acid*, which has been previously fused and powdered, and the two are heated together in a copper tube, at a temperature of about 300° Fahrenheit, they suddenly become red hot; and when the product has been washed with warm water, a greenish-brown, or olive-coloured substance remains, which is *boron*.

It is insoluble in water, tasteless, and without action upon vegetable colours. It is a non-conductor of electricity. It may be exposed to the strongest heat in close vessels without undergoing any change, except becoming harder and more dense. It does not decompose water, either hot or cold. Its specific gravity is about 2. When heated to about 600° Fahrenheit, in the open air it burns vividly, and is converted into boracic acid.

Compound of Boron and Oxygen.

§ 633. Boron absorbs about 68 per cent. of oxygen during its conversion into *boracic acid.*

Boracic acid is commonly obtained by dissolving a given weight of a salt called *borax*, (which is imported into this country from India, in a rough state, under the name of *tincal,*) in boiling water, and adding half its weight of sulphuric acid, previously diluted with an equal quantity of water. As the solution cools, scaly crystals are precipitated, which is the substance in question. It is also found native in the neighbourhood of volcanoes.

It is destitute of odour, and possesses very little taste. It is sparingly soluble in water, and the solution reddens blue vegetable colours. It also acts as an alkali upon turmeric paper, turning its yellow tint to brown. It is soluble in alcohol, and communicates a green colour to its flame. It fuses when heated, and parts with its water of crystallization. There is some difficulty in fixing the equivalent of boron and of this acid; but the latter is probably composed of:—

Boron	29.41	=	1 Equivalent.	20
Oxygen	70.59	=	6 Equivalents.	48
	100.00			68

Formula, $(B^n+6\,O)$.

The number, 68, will agree with the proportion in which it combines with soda, to form borax. The aqueo-acid will then consist of:—

Anhydrous Boracic Acid	55.74	=	1 Equivalent.	68
Water	44.26	=	6 Equivalents.	54
	100.00			122

Formula, $(B^n+6O)+6\ (H+O)$.

Compound of Boron and Chlorine.

§ 634. The *chloride of boron* may be prepared by exactly similar processes to those which have been described for procuring chloride of silicon, (§ 630,) only substituting boracic acid for silica.

It is a colourless gas, which may be obtained in a state of purity by collecting it over mercury, which absorbs any excess of chlorine. It is rapidly absorbed by water, but with instant decomposition, and the production of muriatic and boracic acids. Its specific gravity is 3.94. Its exact composition has not yet been accurately determined. It forms a liquid compound with ammonia.

Boron and Fluorine.

§ 635. If fluor-spar be mixed with half its weight of vitrified boracic acid instead of silica, (§ 631,) and gently heated with sulphuric acid in a retort, a gas may be collected over mercury, which greatly resembles the fluo-silicic gas. It may also be obtained by exposing a mixture of boracic acid and fluor-spar together in an iron tube to a high heat. It is colourless, possesses a very pungent odour, and instantly extinguishes flame. It occasions a dense white cloud when it escapes into the air; and it is rapidly absorbed by water, which takes up 700 times its volume. Some boracic acid is deposited during the solution. 100 cubic inches of the gas weigh about 72 grains. The saturated solution is perfectly limpid, fumes when exposed to the air, and is very caustic. It acts with all the intensity of sulphuric acid upon organized bodies, blackening and disintegrating them. It has no action upon glass, but it forms secondary combinations with ammonia and other bases.

It is most probable that this acid is a compound of boron and fluorine, and it should therefore be called *fluoride of boron*, but its exact constitution has not yet been accurately determined.

CONCURRENCE OF FORCES.

§ 636. The preparatory view which we have now taken of the most striking properties of different kinds of matter, both simple and compound, and of the great laws of definite, multiple, and equivalent proportions, which limit the action of the force of affinity, and which we have found maintained in every case of composition and decomposition, will enable us to proceed to the examination of the more complicated phenomena of *concurring forces*. Some of these have not been without influence in the results which we have hitherto considered as produced by affinity alone, but we were not previously prepared to distinguish and appreciate them.

The forces of *homogeneous cohesion*, and its antagonist, *repulsion*, and the force of *heterogeneous adhesion*, modify, in many instances, very materially the action of affinity.

We will endeavour to illustrate these interferences, first, with the more simple cases of both.

§ 637. We have already (§ 420,) adverted to the fact that the difficulty of determining the combination of carbon with oxygen, or its combustion, increases with its cohesion, from the easily ignited tinder to the diamond.

The metals, iron, copper, and lead, resist the action of atmospheric air, when in mass, very completely; becoming at most only slightly tarnished with oxides; but in a disintegrated state they are acted upon with great energy, and often present the phenomena of combustion.

Finely-powdered oxide of iron may be reduced to the metallic state by placing it in a tube, making it red hot, and passing dry hydrogen gas over it. When the metal which has been thus produced and allowed to cool, is suddenly exposed to the air, it recombines with oxygen and becomes red-hot.

When copper is fresh precipitated from sulphate of copper upon the surface of iron, it is in a pulverulent state, and when washed and exposed to a gentle heat to dry, it will often suddenly ignite and burn into oxide.

When finely-divided lead is prepared by exposing the salt which it forms with tartaric acid to a red heat, in which case the oxide is reduced by carbon, and it is afterwards exposed to the air, it combines with oxygen with the extrication of light and heat.

Pure alumina, as it exists in *corundum*, and some of the Oriental gems, is one of the most untractable substances in nature. It resists the action of all acids, and is with very great difficulty disintegrated by the repeated action of potassa at a red heat. The same substance, as it is fresh precipitated in light flocks, from its saline combination in alum by carbonate of potassa, is readily dissolved, either by solution of potassa, or by sulphuric acid.

The counteracting power of heat upon the cohesion of solids promotes their combination with other bodies, independently of that exaltation of the force of affinity which determines composition at high temperatures; and we have, on the contrary, already noticed cases of decomposition from the mere increase of repulsive force in gases from accession of heat.

§ 638. The mode in which the force of *adhesion* acts in liquids by counteracting, on one hand, the cohesion of solids, and on the other, the self-repulsion of gases is too obvious to require further illustration. The solvent power of water is particularly useful in bringing bodies within the sphere of the attraction of affinity; being a stable compound, and devoid of any very active properties, it does not often exercise disturbing influences upon the results.

§ 639. The force of adhesion in solids acts in a similar, but less obvious way. The strong affinities which the gases exert in what has been called their *nascent state*, are referrible to this cause. If chloride of silver be suspended in water, and a current of hydrogen be directed through the mixture, no change will ensue; but if some pieces of zinc be thrown into the liquid, and a little sulphuric acid added, the chloride will be decomposed, and the silver thrown down. The hydrogen, on its first extrication, is momentarily coerced by the force of adhesion on the surface of the zinc, and has time to exert its superior attraction for the chlorine.

If a perfectly clean plate of platinum be introduced into a long tube filled with oxygen, over pure water, and hydrogen, in the proper proportions to form water, combination will begin slowly to take place, and the water will rise in the tube. The platinum will become warmed by the heat evolved, when the combination will proceed more rapidly, and the metal will ultimately become red-hot, and explode the remainder of the gases. The force of adhesion of the gas to the metal suspends, upon its surface, the self-repulsive force of the similar particles of each gas, and brings them within the influence of the mutual affinity of their dissimilar particles; the combination, thus commenced, proceeds with greater activity as the affinity becomes exalted by the heat.

When the metal is in a disintegrated, or spongy form, it exposes a larger surface to the action of the gases, and becomes proportionately more active; this property has been applied in the construction of an instantaneous-light machine, in which a stream of hydrogen, thrown through the air upon a small quantity of spongy platinum, becomes ignited by the incandescent metal.

§ 640. Many other compositions, decompositions, and recompositions may be determined by the same means.

Ammonia, or any of its salts, when mixed with atmospheric air, is decomposed when passed, at a temperature of about 572° Fahrenheit, over spongy platinum, and the nitrogen which it contains is completely converted into nitric acid by combination with the oxygen of the air.

On the other hand, when the oxides of nitrogen or nitric acid are mixed with a sufficient quantity of hydrogen gas, they are converted into ammonia by contact with spongy platinum, and frequently without the assistance of heat. The action is often so energetic that, if caution be not used, violent explosion ensues. An excess of nitric acid gives nitrate of ammonia.

In the same way, cyanogen and hydrogen give hydro-cyanate of ammonia. A mixture of olefiant gas and deutoxide of nitrogen in excess when hot, and passed over spongy platinum, produces carbonate and hydrocyanate of ammonia and water; and the vapours of nitric acid mixed with hydrogen, may be totally converted into acetic ether and water at a moderate temperature.

§ 641. Platinum, precipitated from its combination with sulphuric acid by boiling in alcohol, is used in Germany upon a large scale for the purpose of manufacturing acetic acid from alcohol upon this principle.

Dishes of earthenware or wood are placed in rows upon shelves, over each other, in a large case. A portion of the black platina powder, moistened, is suspended over each dish, and as much vinous spirit put into them as the oxygen of the included air may be adequate to acidify. In this way 1000 cubic inches of air can oxygenate 110 grains of anhydrous alcohol, converting them into 122 grains of pure acetic acid and 64½ grains of water. The apparatus is set in a light place at a temperature of from 68° to 86° Fahrenheit, and the evaporation of the spirit is promoted by hanging several leaves of porous paper in the case, with their lower edges dipped in the spirit. The action is manifested by an increase of temperature and a generation of acid vapours, which condensing on the sides of the case, trickle down in streams to the bottom. When the oxygen has been all consumed, the process may be renewed by opening the case a little, and replenishing it with air.

With from 7 to 8 ounces of the platinum powder in a box of 12 cubic feet capacity, one pound of alcohol may thus be converted in a day into pure acetic acid. The platinum powder does not waste or become deteriorated by the process.

§ 642. An admixture of other porous substances does not destroy this property of spongy platinum, and pellets composed of clay and finely-divided platinum are very conveniently used to analyze mixtures of inflammable gases and oxygen, by thus determining their combination over mercury.

Other metals also possess this influence, but require to have their temperature raised in various degrees; only those which, like platinum, have a small affinity for oxygen, enjoying it in the same degree. Even non-metallic bodies, as pounded glass and charcoal become efficient at a temperature of 600°.

§ 643. It is probable that the concurrence of this force of adhesion with affinity determines the combination of the nitrogen and oxygen of the atmosphere, and the formation of nitre and other salts of the nitric acid, which effloresce in abundance upon certain soils which contain potassa and other bases in sufficient abundance; and we trace the same kind of action in the formation of crystals of sulphate of ammonia upon the glass windows which are exposed to the action of the coal-impregnated atmosphere of our metropolis.

§ 644. There is a strong analogy between these phenomena and the conversion of sugar into alcohol by the presence of a foreign body, such as *yeast*, (§ 498,) which itself undergoes no change whatever; and to a similar action may also be referred the decomposition of binoxide of hydrogen and bi-sulphuret of hydrogen by metallic oxides, metals, and other foreign bodies, which we have formerly noticed (§ 490, 591).

In the decompositions and recompositions of organic substances also, we often trace the influence of a force which falls short of chemical affinity, but by which it is determined and directed; as, for instance, in the formation of sugar from lignin, (§ 517,) or of ether from alcohol, (§ 504,) under the influence of sulphuric acid, which undergoes no change during the process, and does not enter into the composition of the product.

It has been supposed that this is a force which has hitherto been undistinguished, and it has, therefore, been proposed to give to it the name of *catalysis*, signifying the binding together of bodies, as *analysis* has been taken to designate their separation; but there is no occasion for the hypothesis of a new force, for all the phenomena may be explained by the action of *heterogeneous adhesion.*

§ 645. The play of concurrent forces is curiously illustrated in the actions and reactions of solutions of acids and bases upon salts, and of salts in solution upon each other. They are often of the most complicated kind, and the conditions of the final equilibrium not easy to develop.

Regarding the matter in a general point of view, when upon a salt, or a compound of an acid and a base, we pour another acid, the base must be considered as divided between the two; and we have two salts and two free acids in solution. Thus, if we take a solution of phosphate of soda and pour upon it sulphuric acid, we shall have sulphate of soda and phosphate of soda, and sulphuric acid and phosphoric acid, all in solution, in some unknown proportions, dependent upon the strength of the various attractive forces. Nothing in this case happens to render the change which has taken place apparent. If, however, we pour muriatic acid upon a solution of sulphate of copper, chloride of copper is formed, and sulphuric acid set free, and all the agents remain in solution as before; but in this case the formation of the chloride of copper is indicated by the change of the colour of the solution from blue, the colour of sulphate of copper, to green, the colour of chloride of copper.

No perfect decomposition of the original salt can thus be effected; for whatever excess of the second acid may be added, the other which is disengaged remains within the sphere of attractive influence, and each opposes the action of the other upon the base which is thus divided between the two. But if cohesion or elasticity in any of the products of the operation should prevail over the adhesive force of the solvent, which keeps them in presence of each other, complete decomposition will be the consequence of the abstraction of one of the active bodies from the field of action. Thus, when sulphuric acid is made to act upon carbonate of soda, the carbonic acid flies off in the gaseous state, and is completely displaced from the soda by the sulphuric acid: or when sulphuric acid is poured into solution of nitrate of baryta, complete decomposition ensues, because the cohesion of the sulphate of baryta which is formed, prevails over the solvent power of the water, and the precipitation of the salt annihilates the influence of its constituents.

This ascendency of elasticity or cohesion, which occasions entire decomposition, may be determined by changes of temperature, in circumstances where it does not previously exist. When sulphuric acid is poured upon dry chloride of sodium, muriatic acid flies off, and nothing but sulphate of soda remains: when on the other hand, it is poured into a solution of the salt in water, partial decomposition only ensues; chloride of sodium, sulphate of soda, sulphuric and muriatic acids, all remain in solution together; but if heat be applied, muriatic acid passes off with the vapour of water, and the decomposition is complete. Again: let sulphuric acid be poured into a hot solution of nitrate of potassa; while hot, the two salts and the two free acids will remain in solution together; but upon cooling the mixture, the sulphate of potassa will crystallize, and the whole of the nitre may be decomposed.

We have just alluded to the result of adding sulphuric acid to a solution of phosphate of soda; it is exactly the same when we add phosphoric acid to sulphate of soda; a partition of the base takes place: but if we evaporate the solution, and raise the temperature to above 600°, phosphate of soda will alone remain; because at this high temperature the phosphoric acid is fixed, while the sulphuric acid passes off in vapour.

§ 646. Similar phenomena attend the presence of two bases in solution with an acid. If to the solution of a salt in water we add another base, the acid will be divided between the two. When to a solution of nitrate of baryta, for example, we add a solution of caustic potassa, nitrate of potassa, and nitrate of baryta, and free baryta and potassa exist in the solution; but as the baryta is less soluble than the potassa it will be gradually precipitated, and complete decomposition will ensue, unless there be water enough to hold the whole in solution.

To a solution of muriate of ammonia, add cream of lime; partial decomposition of the muriate will take place, and free ammonia may easily be detected in the solution: heat the mixture, and the lime will totally displace the ammonia; because, as the latter is liberated, it instantly passes off with the vapour of the water.

The same kind of adjustment between acids and bases takes place when the solutions of two salts are mixed together; and four salts will exist in the solution, if no precipitation take place. Thus, on mixing solution of sulphate of copper and chloride of sodium, we know that chloride of copper is formed by the change of colour from blue to green, and consequently that an equivalent quantity of sulphate of soda must also be formed.

To what extent this change takes place, we do not know; for we are unacquainted with the relative force of attraction between the several principles. Thus, when two acids and two bases meet together in equivalent proportions, we conclude that each acid unites with equivalent proportions of both bases, and four salts are contained in the solution; three acids and three bases in like manner give rise to nine salts, and four and four to sixteen.

If, for example, we add together solutions, containing:—

Sulphuric acid	40	parts.
Nitric acid .	54	„
Potassa . . .	48	„
Soda . . .	32	„
Total . .	174	

Or solutions, containing:—

Sulphate of soda	72	parts.
Nitrate of potassa	102	„
Total. . . .	174	

Or:—

Sulphate of soda .	36	parts.
Sulphate of potassa	44	„
Nitrate of soda . .	43	„
Nitrate of potassa .	51	„
Total	174	

The final result will be the same. The last four salts will all exist in the solution, in some proportion dependent upon the relative force of the attractions which is unknown.

But, if we now concentrate the solution by evaporation, the sulphate of potassa will be the first to crystallize, owing to the ascendency of its cohesive force; a new partition of acids and bases will take place between the nitrate of potassa and sulphate of soda, and in this way the mixture will be entirely resolved into:—

Sulphate of potassa	88
Nitrate of soda . .	86
Total	174

§ 647. It is thus that many cases of, what would at first appear to be, *double elective affinity* may be explained; they depend very often upon the forces of cohesion and adhesion, rather than upon the simple relation of the affinities of the different acids and bases concerned: and with an accurate knowledge of the relative solubility of the different salts, or their relative attraction for water, we may always anticipate the decompositions which will follow upon mixing their solutions. If, by a mutual exchange of their acids and bases, a salt can be formed of less solubility than the others, double decomposition will certainly take place, and the less soluble salt will be precipitated, unless there should be sufficient of the liquid present to take it up. Thus, upon adding sulphate of soda to nitrate of baryta, we know that sulphate of baryta and nitrate of soda will result; sulphates of soda and baryta, and nitrates of soda and baryta, will all be formed at first, but the sulphate of baryta will be at once withdrawn from the sphere of action by precipitation. The originally formed nitrates of soda and baryta, and sulphate of soda will momentarily be left; but a fresh arrangement and balance must take place: another portion of sulphate of baryta must be formed, by the reaction of the sulphate of soda and nitrate of baryta, and will again precipitate; till the whole of the sulphuric acid and baryta are thus withdrawn, and nothing remains in solution but nitrate of soda.

§ 648. This partition of a substance between two active affinities, and the concurrence of extraneous forces in producing chemical results, may be exemplified in primary combinations as well as secondary.

When a current of vapour of water is passed over red-hot iron, the water is decomposed, oxide of iron is formed, and hydrogen gas evolved. On the other hand, when hydrogen gas is passed in a continuous stream over red-hot oxide of iron, water is formed, and metallic iron produced. Here, if we take into account the mere force of affinity, the facts appear to be contradictory. In the first, the affinity of iron for oxygen, at a red heat, appears to be greater than that of hydrogen—in the second less: but they may be thus explained:—when hydrogen gas comes in contact with the oxide of iron, the oxygen divides itself between the hydrogen and the iron, in some proportion dependent upon the relative force of the two affinities. The quantity of water thus formed between the first portions, although possibly small, is immediately carried out of the sphere of action by its own elastic force, or by the continued current of hydrogen, and a similar partition takes place between successive portions, till the whole of the oxygen is ultimately abstracted from the iron. A similar partition takes place when steam is passed over the iron, and the disengaged hydrogen flying off ceases to exert its attractive force upon the oxygen, which becomes fixed by its combination with the iron.

Similar instances abound amongst the operations of chemistry: but one more of an exactly parallel case of secondary affinity will complete our illustrations. By passing a current of sulphuretted hydrogen over bi-carbonate of potassa, the carbonic acid will be gradually displaced, and total decomposition will ultimately be effected: on the other hand a current of carbonic acid gas passed through hydro-sulphuret of potassa will displace the hydro-sulphuric acid by successive portions. It must, however, be remarked, that such decompositions require quantities of the displacing agent far greater than would be necessary to saturate the base, or combine with the element.

§ 649. It must not, however, be inferred from these observations that decompositions never take place from the simple action of pure elective affinity; it would not be easy to select many cases which would be entirely free from the influence of concurrent forces, but a striking instance of it may be presented in the action of chlorine and hydro-iodic acid, both in the gaseous state. When the two gases are mixed, the chlorine abstracts the hydrogen from the hydro-iodic acid, and the iodine makes its appearance as a purple vapour.

§ 650. With regard to solutions, the phenomena must of course vary with the nature of the solvent. Thus, carbonate of baryta is readily decomposed by dilute nitric acid; carbonic acid makes its escape, and nitrate of baryta remains in solution: but strong nitric acid will not decompose the carbonate, because nitrate of baryta is not soluble in the concentrated acid.

It is not easy to bring other solvents into comparison with water; for they are mostly endued with strong chemical affinities, in addition to the force of adhesion which they exert upon the saline compounds. Muriatic acid gas dissolved in anhydrous alcohol will not decompose carbonate of potassa, although it will act upon the carbonates of baryta, lime and soda.

Nitric acid mixed with pure alcohol will not act upon carbonate of potassa. Tartaric acid in alcohol will decompose no carbonate.

Oxalic acid dissolved in the same way, will decompose the carbonates of magnesia, strontia and baryta, but not the carbonates of lime and potassa.

It would be difficult perhaps to determine whether in these cases the hydro-carbon of the alcohol acts as a base, or whether, which is the most probable, the difference depends upon the differences of solubility of the different secondary compounds in the solvent employed. In all such instances it is clear that, in estimating the play of forces, the forces of cohesion and adhesion must be taken into account.

§ 651. We have already alluded to the concurrence of *heat* in chemical phenomena, and have distinguished its two functions of acting, first, simply as a repulsive force opposed to cohesion, or the attraction of homogeneous bodies; and, secondly, of exalting the mutual affinities of heterogeneous substances. The latter is by far the most interesting, but stands most in need of further elucidation.

Different degrees of heat are required to determine the combination of different bodies, and different degrees of heat will determine the same bodies to combine together in different proportions. Thus, when a mixture of the vapour of ether and common air is exposed to a white heat, or the temperature of flame, it bursts into flame, and the products are water and carbonic acid, and possibly some free carbon: but if the same mixture be exposed merely to a red heat, as by immersing in it a coil of platinum wire heated to that temperature, combination takes place without flame, and a powerful pungent acid vapour is generated, which has been called the *lampic acid*, and which may be condensed into a liquid by cold. It is probably a mixture of acetic acid and *formic acid*, in which the carbon and hydrogen are not fully oxidated, and which has so strong a remaining affinity for oxygen, that it will take it from certain oxides of the metals in saline combination, and reduce the metal.

When a mixture, again, is made of cyanogen and oxygen, and exposed to the action of flame or of an electric spark, the carbon is converted into carbonic acid, and the nitrogen disengaged; but by the influence of red-hot platinum carbonic acid is produced, and deutoxide of nitrogen, which is immediately distinguished by the red vapours which it forms with a portion of the uncombined oxygen. The different products of the slow and rapid combustion of phosphorus are also instances of the same modified action. It is remarkable that both the processes of slow combustion and rapid inflammation disengage exactly the amount of heat, which is necessary to the respective maintenance of each.

§ 652. It is probable that something like the law of multiple proportions may be maintained in the quantities of heat which are evolved by different bodies during the act of combustion.

According to recent experiments the same quantity of ice is melted when 100 parts of oxygen combine with carbon to form carbonic acid as when they combine with hydrogen to form water. The same result is also obtained when an equal quantity of gas is consumed in the combustion of wood, wax, rosin, and alcohol: but when an equal quantity enters into combination with phosphorus, to form phosphoric acid, a double quantity of ice is melted.

§ 653. It is worthy of remark, that the combinations which take place with the most energetic development of heat and light, when the elements act upon one another directly, result quietly and with but little accession of temperature when they are formed by double decomposition, or even by the single substitution of one body for another in a compound. The most concentrated artificial heat with which we are acquainted is that which arises from the combination of oxygen and hydrogen; but when the two elements separate from their combinations with sulphur by elective affinity, they unite without any of the phenomena of combustion; and when sulphuretted hydrogen and sulphurous acid are mixed together, the sulphur of both is precipitated, and water formed, without the evolution of heat. In the same quiet way chlorine may be substituted for sulphur, or iodine or bromine in combination with hydrogen.

§ 654. We have seen that matter of different kinds,—of different chemical composition, and of different mechanical structure,—exerts a powerful action upon *light* and radiant heat, and from the general principles of action and reaction we might be led to expect that these radiant forces would not be without an influence upon the structure and composition of matter.

Accordingly we find that light is capable of acting upon and directing homogeneous attraction, and of influencing the crystallization of certain substances. Evidence of this may very commonly be found in druggists' shops; where, in the glass jars which contain camphor, and are placed in the windows, beautiful crystals may generally be seen attached to the sides the nearest to the light. Many other substances which are capable of the same kind of sublimation exhibit the same phenomena in their solidification.

M. Chaptal first made the observation that, when a number of capillary crystals shoot up the sides of a glass vessel containing a saline solution, they attach themselves only to that side of the vessel which is most strongly illuminated. He was thus able to cause crystals to form on any selected side; and by placing a screen before the vessel, he found that the line between light and darkness was distinctly marked by the limit of crystallization. This result is most readily obtained with the metallic salts.

§ 655. Light and radiant heat exert, also, a very marked, and sometimes energetic, influence upon chemical affinity; determining the combination of some bodies, and the decomposition of others. If a piece of silk be dipped in a solution of chloride of gold, and kept moist and exposed to the rays of the sun, it will gradually change from yellow to green, and then to purple; spangles of gold will make their appearance upon it, and at the expiration of an hour it will be entirely covered with a film of metallic gold. Professor Seebeck steeped a piece of filtering paper in a moderately-strong solution of gold, and, cutting it in three pieces, he placed one in a dark place; the second he exposed to the rays of the sun, but placed it also in a dark place before it had undergone any change; the third he exposed fully to the sun. The first underwent no change whatever, while both the second and the third had the gold equally reduced upon them.

A solution of nitrate of silver in contact with organic matter undergoes similar changes by exposure to strong light. If a piece of paper be moistened with nitrate of silver, and exposed to the beams of the sun, a very few minutes are sufficient to change the colour to almost black: an effect which is well known from its application as an indelible ink for marking linen.

Chloride of silver retains its snow-white colour and lustre if carefully excluded from the light; but if exposed to the sun, the concentrated light of lime in the flame of the oxy-hydrogen blowpipe, the flame of the voltaic battery, or even to the diffused white light of the clouds, speedily turns to a purplish black colour. This is owing to the decomposition of water, and the formation of muriatic acid and oxide of silver.

That these effects arise from the agency of the radiant forces alone, and not from the influence of mere exalted temperature, has been proved by enclosing the several substances in glasses covered with black paint, and exposing them to the sun; in which case they become very hot, but even after several days no chemical effect was produced.

§ 656. Many years ago it was proposed by Mr. Wedgwood and Sir Humphry Davy to apply this chemical influence of light to the tracing of objects by means of their shadows, or to the copying of drawings by the agency of the light transmitted through them in different degrees. They succeeded in obtaining such tracings by means of paper prepared with nitrate or chloride of silver; but they failed in their attempts to fix them in such a way as to render them afterwards unchangeable in the light. Mr. Fox Talbot has lately attained this object; and by placing prepared paper in a small camera-obscura, he has been enabled, in a few minutes, to obtain most perfect, but extremely small, pictures,—such as, without great stretch of imagination, might be supposed to be the work of some Lilliputian artists. They require, indeed, examination with a lens to discover all their minutiæ. Engravings and sculpture may thus be copied with the utmost fidelity, and the process appears to be applicable to a variety of useful purposes, such as the delineation of objects in the solar microscope, &c. A process of the same nature was some years ago invented in France by M. Niepsce, and has just been brought forward by M. Daguerre of Paris, who is said to have made some considerable improvements upon it; but neither of these gentlemen have yet published the preserving process in which the great merit of their application consists. This purpose, however, may be effected by washing the paper upon which the design has been imprinted with a solution of *hypo-sulphite* of soda, which dissolves out the unchanged nitrate or chloride, without affecting the dark parts in which the change has been produced. In these *heliographic* drawings, as they have been named, the effects of light and shade are all reversed; but by a second process, in which the light is transmitted through the first design upon a second prepared paper, this defect may be rectified. In M. Niépce's process, it is understood that the lights and shades correspond with those in nature.

§ 657. The operation of bleaching linen affords another familiar illustration of the chemical changes which light is capable of producing. Every washer-woman is aware from experience that this process most readily succeeds in bright weather. The removal of colour is, probably, ultimately referrible to the decomposition of water, and the consequent disengagement of oxygen.

§ 658. The instances in which light promotes combination are equally striking.

We have already stated that, when hydrogen and chlorine gases are mixed together, they enter very slowly into combination in a feeble light; but, when exposed to the direct rays of the sun, combination is extremely rapid, and not unfrequently attended with explosion.

Chlorine and carbonic oxide can be made to unite together by no other influence with which we are acquainted, and hence the product has been called *phosgene gas.* They are introduced for this purpose in equal volumes into an exhausted flask, and exposed for a quarter of an hour to bright sunshine. The colour of the chlorine gradually disappears, and the gases are condensed into half their united bulk. The new gaseous body has an intolerably pungent odour, and greatly affects the eyes. It reddens litmus, and by contact with water is resolved into carbonic and muriatic acids. It condenses four times its volume of ammoniacal gas, and the product is a white neutral salt, from which the more powerful acids disengage carbonic and muriatic acids.

§ 659. All the rays of the solar spectrum are not equally endued with this influence upon chemical affinity; for when they fall upon paper impregnated with chloride of silver, the chloride becomes blackened much sooner in the violet than in the other coloured rays. The power seems to extend even beyond the limits of the violet light itself, as if it belonged to certain highly refrangible dark rays analogous to the little refrangible dark rays of heat at the opposite extremity of the spectrum. These chemical rays may be separated by absorption, as well as by refraction: for if a neutral solution of chloride of platinum be mixed with lime water, and a portion placed in two clear glass tubes, one of which is immersed in a blue solution of ammonia-sulphate of copper, and the other in a red solution of cochineal, oxide of platinum and lime will be precipitated from the former, while the latter will be protected from all change.

§ 660. The most intense light from the combustion of the hydro-carbons produces no change upon chloride of silver, nor yet on a gaseous mixture of hydrogen and chlorine; but the light from the voltaic battery, and that from lime heated in the oxy-hydrogen blow-pipe, when concentrated by a glass lens, speedily blackens the chloride.

§ 661. The processes of *vegetation* are also greatly under the influence of the same subtle agency. The artificial exclusion of light from plants gives rise to the effect upon them, which is called *etiolation*, or *blanching*. Under such circumstances they always extend their branches and shoots towards any opening at which light is partially admitted; and if this be closed, and another opened in a different situation, they change their direction, and still turn towards the luminous influence. If kept in perfect darkness they become feeble, succulent, insipid, and of a white or yellowish colour; but if in this state they be transferred to a situation where they may enjoy the action of the solar rays, they regain their green colour and become vigorous. According to the observations of Sennebier, the green colour of the leaves of plants is more readily developed under the influence of violet light than under that of any other colour.

§ 662. We will close this summary view of the relations of light to matter with a few observations upon the different degrees with which it seems to be absorbed and retained by some bodies. There are substances which appear to be capable of emitting light at a very moderate accession of temperature, without undergoing any sensible chemical change. The diamond, for instance, fluor spar, and various other bodies, possess this property in various degrees. It is called *phosphorescence*, but is very different from the luminous property possessed by phosphorus, which, as we have seen, is due to a slow combustion at a low temperature. These bodies lose the property of emitting light when they have frequently been made to undergo the process; but may have it restored, by passing through them strong electric discharges, which, in some cases, will confer the property upon substances which did not previously possess it. Some species of fluor spar *(chlorophane)* become so light in boiling water as to enable a person to distinguish the letters of a book.

§ 663. Another class of bodies first absorb light from an extraneous source, and give it out again upon being taken into a dark place: these are sometimes distinguished as *solar phosphori.* The most powerful of these is an artificial compound first made by Canton. It may be formed by mixing three parts of calcined oyster-shells in powder with one of flowers of sulphur, and igniting the mixture strongly for half an hour in a crucible. On picking out the lighter coloured parts, and exposing them to the sunbeams, to common daylight, or to the light of an electric explosion, they will acquire the faculty of shining in the dark, so as to illuminate the dial of a watch and make its figures visible. After a time it will cease to shine; but if kept in a well-stopped phial, a fresh exposure to the sun will at any time restore the luminous property.

§ 664. Some species of animal and vegetable matter, in a state of decay, have the property of emitting light,—particularly some marine fish and crustacea, such as lobsters. The quantity of light given off by such substances is by no means proportioned to their degree of putrefaction; but, on the contrary, the greater the putrescence the less light they generally emit.

§ 665. The power which certain living animals possess of emitting light at their pleasure, properly falls within the province of the science of PHYSIOLOGY for examination and explanation. We have the less reluctance, indeed, to pass over with a brief allusion, the interesting phenomena which the *glow-worm* and the *fire-fly* present, inasmuch as they at present remain amongst the most inexplicable of the products of LIFE. The superficial waters of the ocean sometimes glow with living fire, emitted from countless millions of minute marine animals who have the privilege of kindling it and extinguishing it at will; while in the eternal darkness of the great deep, to which the rays of the solar orb can never penetrate (§ 221), the larger animals are lighted to fulfil the purposes of their being, by a process which appears at present to be amongst the most inscrutable wonders of the Creation. Our knowledge of *Animal Chemistry* scarcely enables us to form a guess respecting the nature of that light which is thus provided for the submarine hosts of beings.

§ 666. The concurrence of the different forces of cohesion, adhesion, affinity, light, heat, electricity, and magnetism, is exemplified in the most marvellous manner in the arrangements and phenomena to which we must next direct our attention; and for the proper understanding of which our previous investigations into the laws of each are no more than a necessary preparation. We must return to the force of affinity, and pass from its local action to consider the phenomena of its current state.

CURRENT AFFINITY.

§ 667. The force of affinity, as we have hitherto contemplated it, has been excited by the contact of the particles of dissimilar kinds of matter; it has been expended at the points at which it originated; and its action has only become continuous by the gradual supply of the active agents, and the removal of the inert compounds by the agency of concurrent forces.

Metallic zinc, when exposed to a sufficiently high temperature, burns in the air with a plentiful evolution of brilliant light and heat; but the process soon comes to an end, if the oxide, which is the product of the combustion, be not removed, and fresh contacts produced between the metal and the oxygen.

A plate of bright zinc, when immersed in water, speedily becomes dulled by the formation of a thin coat of oxide; but the oxidation proceeds no further, because the adhesion of the oxide prevents a renewed contact of the metal and the water.

When a little sulphuric acid is added to the water, the oxide is removed by secondary combination as it is formed; the oxidation goes on with rapidity at the fresh surfaces of contact, and the hydrogen of the decomposed water is carried out of the sphere of action by its elastic force.

§ 668. If the surface of the zinc plate be carefully amalgamated with mercury, a new play of forces is produced. Upon introducing the plate into the dilute acid, its surface becomes covered with bubbles of hydrogen gas, which adhere with considerable force, and will not rise through the liquid; the force of adhesion is sufficient to counteract their elasticity. The metal is thus protected from further action; or rather its affinity for the oxygen of the water is held in check by the affinity of the nascent hydrogen, which is competent to deoxidate the oxide when once formed. If the bubbles be carefully brushed away as they are produced, the oxidation of the zinc and the decomposition of the water will proceed.

§ 669. It can scarcely be necessary to remark that these compositions and decompositions all take place in equivalent proportions: 32 parts or 1 equivalent of zinc combine with 8 parts, or 1 equivalent, of oxygen; and the 40 parts or 1 equivalent of oxide are taken up by 40 parts, or 1 equivalent, of sulphuric acid. Eighty parts of sulphate of zinc are thus formed; from which 48 parts, or 1 equivalent, of potassa will throw down 40 parts of oxide of zinc, and 32 parts of zinc evolve 1 part of hydrogen from the water, by its action on the dilute sulphuric acid.

§ 670. All these actions are local; but we have it in our power to cause this same force of affinity to travel: we can send it to a distance, and oblige it to act at points far removed from that at which it is excited or generated. Some of the results will be manifested, as before, by decompositions and recompositions of matter; but not confined, as heretofore, to the point from which the force is set free; and new forces will be developed. The impulse must be given and maintained by the contact of dissimilar particles of matter; but it may be communicated to points very distant from those at which it originates.

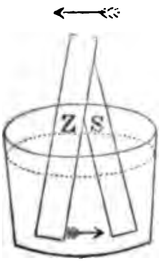
§ 671. The analogy of the transmission and direction of mechanical force may, perhaps, assist in the formation of a clear idea of this influence of bodies where they "are not." Every one is familiar with the modes by which the muscular force of animals, the elastic force of steam, or the wind, or the attraction of gravitation, is led by the solid matter of levers, cords, and wheels, to distant points from its source, and there set to work: somewhat in the same way we may conceive that the force of affinity may be directed to distant points through appropriate conductors. But its journeyings must be in a circle, and the arrangement must be made in such a way that the impulse may return to the point from which it set out:—it must *circulate*. Actions so remote from all common experience can only be elucidated by experiment, and the results of the careful observation of facts in circumstances purposely contrived and varied.

§ 672. We have already stated that, when an amalgamated zinc plate is immersed in water acidulated with sulphuric acid, the incipient action is soon arrested by the adhesion of bubbles of hydrogen: a second plate introduced into the same portion of liquid will, of course, not act differently, whether it be in contact with the first or not. If, instead of a second plate of zinc, a plate of platinum or silver be placed in the acid, nothing occurs so long as the two plates are kept separate; but if they touch one another in any point, the zinc immediately begins to take oxygen from the water. The equivalent hydrogen is not now, however, given off upon its surface, but upon the surface of the platinum or silver, even at its most remote points; being thus removed from the point of contact between the zinc and the acidulated water, it no longer suspends their action, and the oxidation of the zinc proceeds.

It is not necessary that the contact between the two metals be made within the liquid; if they be only partially plunged into it—if the parts immersed be separated by a considerable interval, and they be brought to touch only by their exterior edges, action immediately ensues, and the hydrogen is evolved only upon the platinum, however distant it may be from the zinc.

Again: contact between the two plates need not take place at all, provided a communication be established between them by means of any other metal; a very fine wire is quite sufficient for the purpose, and will be efficient even in lengths which may be measured in miles. The necessary condition is, that the connexion be made by some good conductor of electricity; and charcoal may be substituted for metal.

If a tube three feet long be filled with the dilute acid, and a wire of platinum be inserted through a cork in one of its extremities, and an amalgamated zinc wire in the other, on connecting the wires hydrogen will be given off upon the former, notwithstanding the distance of the two metals (138).



(138) In this figure, z represents a zinc plate, and s one of silver, immersed in a vessel of dilute sulphuric acid. As long as they are in contact by their upper extremities, the zinc will be oxidated and dissolved, and the silver will be covered with bubbles of hydrogen, which will quickly rise from its surface.

The force which originates with the zinc passes in the direction of the lower arrow, from z to the silver plate s, and returns from s to z in the direction of the upper arrow.

§ 673. Now it is obvious that the origin of the action must be an attraction of zinc for oxygen superior to that by which oxygen is combined with hydrogen in water. That the force thus generated travels through the liquid, is proved by the extraordinary transfer of the disengaged hydrogen to the opposite plate, which by itself has no attraction (or the least possible) for oxygen or hydrogen; and that it returns through the conducting solid to the zinc, we conclude from the whole remaining in abeyance till the communication is complete.

§ 674. We can, moreover, produce evidence that the conducting wire is in a state of activity, while transmitting the impulse, very different from its ordinary state. If the communication between the generating and the conducting plates, as we may call them, be made by means of the fine wire in the air-thermometer which we have before described (§ 337), it will be found to evolve heat; and if the wire, or any part of it, be very much reduced, or the plates be greatly enlarged, the wire will become ignited at its thinnest part, and even fused.

Different metals become heated in different degrees, and hence, their difference of expansion which increases with the temperature, as measured upon a Breguet's thermometer (§ 144), will afford a measure of the exciting cause.

§ 675. Every part of the wire, when in connexion with the two plates, is also capable of exerting a powerful action upon the magnetic needle. If the needle be allowed to take its natural position

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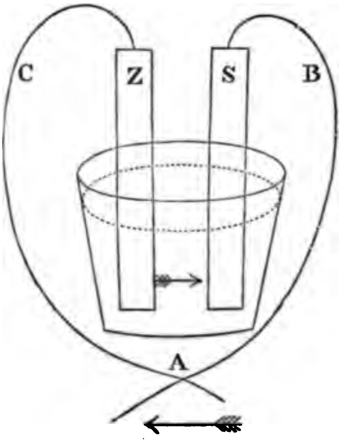

If instead of being in immediate contact, as in the last figure, the plates be connected with the wires, C A, B A, the same effects will be produced; but if the metallic communication be interrupted for a moment at A, all chemical action will be terminated.

under the directive power of the earth, and the wire be placed above it in a parallel direction, the end which points to the north being directed towards the silver plate, that end will move towards the west, and the needle will tend to place itself across the wire: but if the wire be placed below the needle, the same pole will move eastward, and cross the wire in the opposite direction. When the position of the zinc and platinum plates, with regard to the needle, is reversed, the direction of the movement of the needle will be also reversed, and its ultimate position will indicate the course of the current (139).

This is not the place in which we propose to inquire into the laws of this magnetic action; it is only at present brought forward to demonstrate, that the wire which connects the two metallic plates in the arrangement which has been described, does in reality transmit a force which manifests itself by very energetic actions. It has also been applied to the construction of a very delicate instrument for measuring the quantities of the extraordinary agent which is thus called into activity, without an explanation of which it is scarcely possible to proceed.

§ 676. Every point of the connecting wire equally influences the magnetic needle, and the force with which it affects it may be doubled by bending it back upon itself, and placing the needle between its two parallel branches (140). If a copper wire be bent

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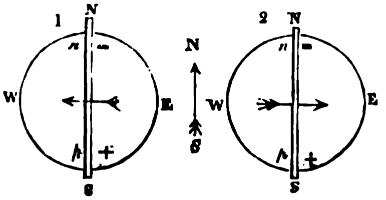
(139) In the annexed diagram, let *p n* represent the conducting wire of the circuit, *n* being in connexion with the silver plate, and *p*, with the zinc plate. Let the natural direction of the needle, under the



influence of the earth, be represented by the arrow, N S, between the two circles. When the needle is placed above the wire, 1, its marked pole will be deflected towards the west, and when placed below the wire, 2, it will be deflected to the east.

(140) The adjoining figure represents a magnetic needle, freely supported upon a point within a rectangle, formed by a wire doubled back, and

into a rectangular form, consisting of several coils guarded from metallic contact by being covered with silk, and in the centre of the rectangle a delicately suspended needle be placed, each coil will add its influence to that of the others, and the needle will be impelled by the joint action of all. If such an arrangement, previous to its connexion with the active plates, be placed so that the rectangular coils be parallel to the needle in the position it occupies under the directive influence of the earth, and the connexion be then made, the effect will be to occasion such a deviation from the plane of the magnetic meridian, as will arise from the balance between the new force acting on it and the magnetic force of the earth. The number of degrees at which the needle stops, measured upon a graduated arc of a circle, will therefore give an approximative measure of the intensity of the force exerted by the wire.

We are not prepared at present to describe the several modes by which the force may be determined with perfect accuracy.

§ 677. An instrument constructed in the manner which we have described is called a *Galvanometer*. Its delicacy may be very much increased by employing two needles attached together, one above the other, in a parallel direction, with their poles in opposite directions. The distance between the needles is such as to allow of the upper part of the coil of wires to pass between them; an opening being left by the separation of the wires at the middle of the coil, for allowing the thread by which they are suspended to hang between them. By this contrivance, the directive power of the earth upon the *astatic needle*, as it is called, is very nearly neutralized, enough only being allowed to remain to bring it to a constant direction, when the wire is in a state of inactivity: at the same time when thrown into action, both the needles are impelled in the same direction. The lower needle being in the situation of the

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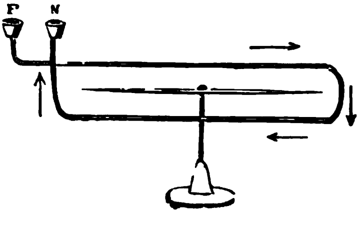
placed in connexion with the zinc and copper-plates of a circuit, by the mercury cups, P and N. By this arrangement the influence of the under part of the conducting wire is doubled upon the needle: for both the parallel lengths conspire to deflect it from its natural position in the same direction, and to bring it into a position nearer to a right angle to the plane of the wire.



more simple apparatus just described, is acted upon by the forces in every part of the coil, while the upper needle is impelled by the contrary influence of the upper side of the wire, but in the same direction as the lower, on account of the reversed position of its poles.

The needle of an instrument so constructed will be sensibly deflected by the immersion of less than $\frac{1}{8}$th inch of zinc wire, $\frac{1}{80}$th inch diameter, and a corresponding length of platinum wire, in a large drop of water acidulated with sulphuric acid.

The galvanometer may be rendered a still more accurate measure by completely neutralizing the influence of the earth upon the astatic needle, and substituting the force of torsion to produce the equilibrium with the force of the active wire. The ease and accuracy with which the former may be measured, renders it a very perfect means of estimating the amount of the latter (141).

§ 678. Every part of a wire, thus forming a communication between a zinc and platinum plate immersed without contact in the same vessel of acidulated water, whatever the metal may be, is endued upon its opposite sides with the opposite forces which are resident in the magnet, and communicable only, as we have hitherto found, to iron and nickel.

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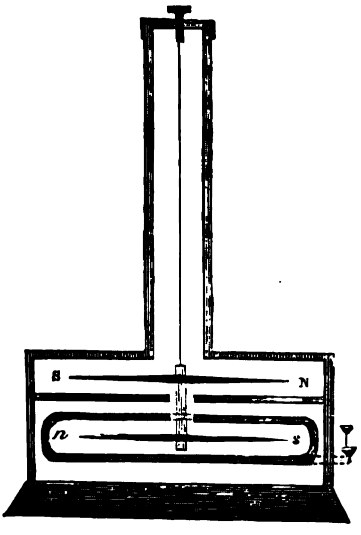
(141) The torsion galvanometer of Dr. Ritchie is here represented. *n s* is the lower needle, surrounded by the coil of wire, and connected with the upper needle S N by a piece of straw which passes through the upper part of the horizontal coil, and through a circular card placed above it, on which a graduated circle is drawn. It is then attached to the torsion filament, which is fixed to a screw, supported by the frame of the instrument. The filament may be of glass, and the angle of torsion, may easily be measured upon the graduated card. The wires of the coil are easily connected with the plates of the circuit, by means of the small mercury cups.



§ 679. The phenomena which occur when a portion of the moist structure of a living animal, or even of one which has been a short time dead, is made the medium of communication between a zinc and conducting plate, and the circuit is completed by a metallic wire, bear testimony to the propagation of some extraordinary force by the latter. The history of the origin of this most important branch of science must, almost necessarily, be included in their description. In the year 1790, Professor Galvani of Bologna, was accidentally occupied with the dissection of a frog, at the time when some other person was experimenting with an electrical machine in its neighbourhood, and observed that, whenever the point of his scalpel was in contact with one of the crural nerves, and a spark was drawn from the machine, violent convulsions were occasioned in the limbs.

We now know that, under these circumstances, the frog formed part of a system of bodies under induction, by the polarization of the particles of which, the charge was sustained upon the prime conductor; when the latter was discharged, their state of tension was relieved, and in returning to their former state, commotion was produced similar to that which takes place with more violence, when an animal is placed in the course of the discharge of a Leyden jar. In seeking to vary the circumstances of the experiment, the explanation of which was unknown to him, Galvani armed the muscles and the nerves with different metals, and found that, whenever a metallic communication was made between the two, similar convulsive movements were produced without the cooperation of the electrical machine (142). The new branch of science which sprang from this capital observation has been called GALVANISM, in honour of the mind which discerned the importance of phenomena of such apparently trifling import.

§ 680. There are many ways now known of varying the experiment. By placing a live flounder upon a slip of zinc with a shilling upon its back, whenever a metallic communication is made between the two metals by a metallic wire, strong muscular contractions are produced in the fish. If a piece of silver be placed upon a person's tongue, and a piece of zinc or lead under it, no effect will be observed so long as the two metals are kept apart; but when their ends are brought in contact, a slight sensation, as from a feeble electrical shock, will be produced, and a peculiar saline taste. If one metal be placed between the upper lip and the gums, upon bringing their ends together as before, the eyes will be affected as by a flash of light. This observation had been made nearly fifty years prior to Galvani's by Sulzer, but excited little attention; although, perhaps, it exhibited the germ of the future science in a more striking form; showing what different fruits are produced by accidental seeds, when they fall upon a mental soil unprepared for their reception, and upon one fitted by proper culture.

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(142) The figure in the next page represents the legs of a frog prepared for Galvanic experiments. The skin is removed, and the crural

§ 681. In these experiments, no effects are observed from separate pieces of metal of the same kind, and the contractions are most powerful when those metals which are most difficultly acted upon by acids are opposed to others which are easily acted upon. The fluids of the animal body act the part of the dilute acid between the plates in the single circuit.

§ 682. We have now to consider how the impulse which is derived from the zinc is transmitted through the liquid to the platinum; and how we may account for the extraordinary fact that the oxygen of a portion of water combines with the former, while the equivalent hydrogen, with which it was associated, is evolved upon the distant surface of the latter.

No visible transfer of the disunited elements takes place, and if

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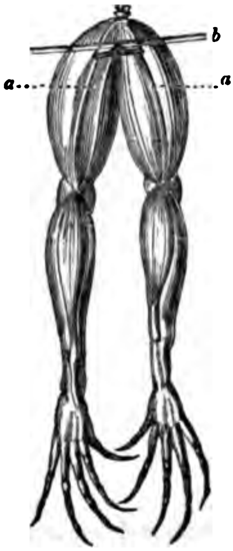

nerves, *a a*, are easily found by gently separating the muscles on the back of the thighs: *b* is a silver wire, passed under both the nerves, by which metallic contact is insured. The legs may be laid upon a plate of zinc; and, when the circuit is completed by a metallic communication between the two metals, violent convulsions are produced.

the vessel which contains the acid be divided by a diaphragm of bladder, or a partition of porous earthen-ware, or other substance capable of imbibing the liquid, and the two plates be placed on its opposite sides, no impediment arises to this extraordinary separation.

The force must be conceived to travel by a species of convection, of which a mechanical illustration again may assist us in forming a first notion. When a number of ivory balls are freely suspended in a row so as just to touch one another, if an impulse be given to one of the extreme ones by striking it with a hard substance, the force will be communicated from ball to ball without disturbing them, till it reaches the most distant, which will fly off under its full influence. Such analogies are but remote, and must not be strained too far; but thus we may conceive that the force of affinity receives an impulse in a certain direction, which enables the hydrogen of the first particle of water which undergoes decomposition to combine momentarily with the oxygen of the next particle in succession; the hydrogen of this again with the oxygen of the next; and so on, till the last particle of hydrogen communicates the impulse to the platinum, and escapes in its own elastic form.

The force thus taken up by the conducting plate, is transmitted along the connecting wire, with the phenomena which we have described, back to the zinc, and thus the circuit is completed.

§ 683. The imperfection of verbal communication obliges us to describe these phenomena as successive, whereas they are in reality almost contemporaneous. The generated force is commonly described as a current, as of some imponderable fluid, flowing from the zinc through the liquid to the platinum, and back again through the wire to the zinc. The current may as easily be conceived to be made up of a succession of impulses, communicated to a distance through appropriate conductors, as of the perpetual generation of a fluid; so, on the other hand, the vibrations of an elastic body might be deemed a current of mechanical force, and all the phenomena of sound explained upon the hypothesis of an acoustic fluid.

The expression, however, of a current is very convenient, and when thus guarded cannot well lead to misapprehension.

§ 684. The amount of force set in circulation, as measured either by the zinc consumed, or the hydrogen disengaged, in given times, or by their instantaneous heating or magnetic effects, is dependant upon the surfaces of the plates immersed in the liquid, supposing them of equal sizes and at equal distances from each other. The amount also decreases with the distance of the plates.

§ 685. If plates of a certain extent of surface, instead of being immersed in one cell of liquid, be cut into several equal pairs and placed in separate cells, and all the zinc plates be connected together by metallic wires, and all the platinum similarly connected, no action will ensue till the two series also are connected together by another wire; but when this has been effected, the amount of circulating force will be sensibly the same as before. A galvanometer placed between any two similar plates, will indicate that the current passes from one to the other, and when placed between the opposite sets, that the currents of all are united in its wire. When arranged in this manner, it is not essential that all the pairs should be of the same dimensions, for the actions of all, however unequal, may thus be combined.

§ 686. It is obvious that a second zinc plate cannot perform the functions of a conducting plate to the first, because it will itself tend to generate a current of exactly equal power in the opposite direction, and the powers at the two places of action being in direct communication will be balanced against each other through the medium of the metals, in a manner analogous to that in which mechanical forces are balanced against each other by the intervention of the lever. But any metal which has a stronger affinity for oxygen than platinum, provided it be less than that of zinc, may be substituted for it. Thus, copper when opposed to platinum is capable of generating a feeble current; but when opposed to zinc will become an efficient conducting plate. Its attraction, however, for oxygen, though counteracted, will act as an antagonist force and check the current.

§ 687. As *current affinity* is thus liable to be checked in its course by the tendency of an opposing affinity, so may it be assisted by the more speedy removal from its circuit of the disengaged hydrogen which, by its adhesion to the conducting plate, still acts as an obstruction to the force; though not to the same extent as when evolved upon the generating plate. This may be effected by the addition to the liquid of a portion of nitric acid; and in this case no hydrogen will be given off, and the energy of the current, as manifested by its heating and magnetic powers, will be greatly increased. After allowing such a charge to neutralize itself, by its action upon the zinc, and evaporating the solution of the salts which are formed, the addition of lime will disengage abundant fumes of ammonia; thus proving that, not only has a portion of the hydrogen combined with the oxygen of the acid to form water, but that another portion has combined also with the nitrogen to constitute the volatile alkali.

§ 688. The hydrogen may also be removed by the action of metallic oxides; for, when under the restraint of adhesion, it is capable of deoxidating and reducing the metals from their saline solutions. A little additional arrangement is, however, necessary to effect this with precision. If a solution of sulphate of copper be merely added to the liquid in the cell which contains the two plates, after the circuit has been completed, the platinum plate will speedily become coated with reduced copper; but a portion of the metal will also be precipitated upon the zinc plate, owing to the hydrogen which still adheres to its surface from the local action: the consequence will be that strong local action will take place upon the surface of the zinc plate, owing to small circuits formed with the copper which attaches itself to it.

If the cell, however, be divided into two equal parts by a diaphragm of bladder, or porous earthenware, and the sulphate of copper be added only to that division which contains the conducting plate, the current will proceed with increased energy, and the hydrogen will be completely absorbed.

§ 689. Notwithstanding the extraordinary modification which the force of affinity undergoes in these combinations, everything is limited by the laws of definite and equivalent proportions. For every 32 grains of zinc expended in the generation of the force, 40 grains of oxide of zinc and 80 grains of sulphate of zinc are formed, and 1 grain of hydrogen is evolved; or else 80 grains of sulphate of copper and 40 of oxide of copper are decomposed, and 32 parts of metallic copper are precipitated by the combination of 8 grains of oxygen with 1 grain of hydrogen.

Moreover, if we compare these effects of chemical force with the effects produced by the associated forces, we shall find that, if a certain amount of these compositions and decompositions take place in a given interval of time, a corresponding effect will be instantaneously produced, either upon the magnetic or calorific galvanometer; and if the chemical effects be augmented, the heating and magnetic effects will be proportionately increased.

§ 690. The local circuits which we have just pointed out as formed by the precipitation of the copper upon the zinc plate, when not protected by a diaphragm, will now explain the action of zinc in its ordinary state, upon dilute sulphuric acid. Perfectly pure zinc acts exactly the same as the amalgamated metal, its surface becomes covered with bubbles of hydrogen, which adhere to it, and put an end to the process of decomposition; but particles of iron, copper, and other metals which are met with in the zinc of commerce, constitute so many points to which the hydrogen is directed by the influence of small local circuits, and the action proceeds. This local expenditure of force does not interfere with that which passes in the principal circuit, and common zinc may be employed for the construction of such circuits, although the metal which is expended in the local action is wasted for the main purposes of the combination.

§ 691. That the circulating force depends entirely upon the decomposition of the water, and the composition of oxide of zinc, and that the sulphuric acid acts only a secondary part in the removal of the latter, is proved by substituting potassa for the acid. The action in this case will proceed in the same direction, but more slowly; and the hydrogen evolved upon the conducting plate, will still be equivalent to the oxygen combined with the generating plate.

The affinities of other substances may be thrown into circulation, and when solutions of hydriodic, or muriatic acid, are substituted for water acidulated with sulphuric acid, iodides or chlorides of zinc are formed, and their hydrogen is directed to the conducting plate. The conditions of this efficiency we shall advert to more particularly hereafter.

§ 692. The most energetic affinity unaccompanied by decomposition cannot, however, be thrown into circulation. The simple and direct combination of zinc with oxygen cannot be made to produce any of the effects of a current, and the decomposition of water, no less than the composition of oxide of zinc, is necessary to this result.

The affinity of zinc for chlorine is so great, that the metal will spontaneously ignite when introduced into the gas, but zinc and platinum have been properly disposed together in liquid chlorine without producing the slightest current. It does not excite a current through the two plates by combining with the zinc, for its particles cannot transfer the force which is active at the point of combination, across to the platinum. It is not a conductor of itself, like the metals; nor is it capable of transmitting the force by that species of convection which we have just described (§ 682); and, hence, there is simple chemical action at the spot, and no current.

The metals themselves, though excellent conductors, cannot alone be made to transfer the force from the point of generation to a distance. Melted lead and tin are capable of combining with platinum with great energy and the evolution of light and heat; but if a bent tube be filled with melted tin, and one extremity be put into metallic communication with one wire of a delicate galvanometer, and a similar communication be made between the other and a plate of platinum, which is afterwards immersed in the tin, the needle will be affected in a slight degree at the first application of the heat, from a cause which will be hereafter pointed out, but will be no further disturbed when the energetic action between the two metals comes on.

§ 693. The affinity of secondary combination may also be thrown into circulation; and if a neutral salt be dissolved in water, and made the medium of communication between a zinc and platinum plate, the acid will pass with the oxygen of the water to the former, and the base with the hydrogen to the latter, where each may be detected by the proper reagents.

§ 694. For the purpose of establishing a current of affinity, it is necessary that the divellent substance be a conductor of electricity, otherwise the force which is developed upon different points of its surface can never travel back to those points from the conducting wire in which it has been collected. But the same metal may perform the functions both of a generating and conducting plate, provided one portion of its surface be immersed into a liquid which it is capable of decomposing, while another is plunged into a liquid to which it is indifferent: both liquids being also in contact with each other.

If a glass tube, of about an inch diameter, be bent into the form of the letter U, and the two legs be separated by a plug of clay, plaster of Paris, or other porous material, upon filling one leg with solution of sulphate of copper and the other with acidulated water, and dipping one end of a bent strip of copper into the first, and the other end into the second, a circuit will be formed. The extremity in the acid will be slowly oxidated and dissolved, and the opposite extremity will become coated with reduced copper, from the action of adhering hydrogen; and if the strip be divided in the middle, and again connected by the wires of a galvanometer, the needle will be deflected in the same direction that it would have been by a zinc plate in the acid. If a solution of potassa or soda be substituted for the solution of sulphate of copper, and a slip of zinc, or tin, or some other metal, be substituted for the slip of copper, a current will also be established (143).

The arrangement of the circuit may be more simple still; for if some solution of sulphate of copper be poured into a straight glass tube, and some acidulated water upon it, so as not to mix the two liquids, upon immersing a strip of copper into both, the lower part will become covered with precipitated copper, while the upper will be oxidated and dissolved.

§ 695. The command which we thus obtain over the force of affinity; the power of regulating both its quantity and the duration of its action; the possibility of directing the evolution of some of the most energetic agents at particular points; and especially the disengagement of hydrogen in a state which enables its all-powerful affinities to act upon surrounding compounds, may be applied to the production of compositions and decompositions which cannot be effected by the more confined and sudden energy of local action. In the simple apparatus of the bent tube, which has been just described, if one leg be filled with a solution of common salt, and the other with some solution of a metallic salt, and a plate of zinc be immersed in the first, and a plate of platinum in the second, on completing the circuit by the metallic communication of the two plates, the metal will be reduced upon the latter. On account of the slowness and regularity of the operation, it will often assume the form of small crystals of the greatest regularity and beauty. Thus, when proto-chloride of iron is submitted to the process, after some days, the iron will be precipitated in very small tetrahedral crystals, which are sometimes so closely grouped together, as to have the appearance of having been melted upon the platinum. Even the oxides of those metals which have the strongest attraction for oxygen, may be reduced by the same slow process. If chloride of

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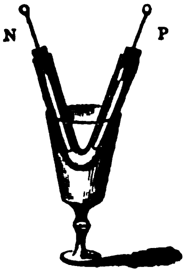

(143) The annexed figure represents the glass tube bent in the manner described in the text. If the lower part be stopped with plaster of Paris, and solution of sulphate of copper be poured into one branch, and dilute sulphuric acid into the other, by immersing a slip of copper into each, and connecting the two ends N and P with a galvanometer, a current will be indicated.

zirconium, mixed with a small quantity of chloride of iron, be operated upon, the platinum plate slowly assumes a gray tint, and, at the expiration of twenty-four hours, brilliant scales of a steel-gray colour will be perceptible. These scales undergo no change in the solution, so long as they are under the influence of the current; but when they are withdrawn, they rapidly oxidate either in the air or in water with the disengagement of hydrogen, and fall into a white powder.

The skilful application of these means has enabled M. Becquerel to obtain a variety of crystallized compounds of different substances, which are sometimes found in nature, but were never before produced by art.

§ 696. Mr. Golding Bird has lately improved the apparatus by which the circulating force may be directed to the production of these effects. A glass cylinder, 1.5 inch in diameter, and 4 inches in length, is closed at one end by a plug of plaster of Paris, .7 inch in thickness; this cylinder is fixed by corks inside a cylindrical glass vessel, about 8 inches deep and 2 inches in diameter. A piece of sheet copper, 6 inches long and 3 inches wide (having a copper conducting wire soldered to it), is loosely coiled up and placed in the small cylinder; a piece of amalgamated zinc, having also a conducting wire soldered to it, is placed in the larger external cylinder. The latter is then filled with a weak solution of common salt, and the former with a saturated solution of sulphate of copper. When the two plates are placed in connexion with the wires of a galvanometer, a feeble current will be indicated, and, after being in action some weeks, chloride of zinc will be found in the external cylinder, and beautiful crystals of metallic copper adhering to the copper plate in the smaller cylinder.

Instead of the galvanometer, this piece of apparatus may be connected with another apparatus, the counterpart of the first; the zinc being put into metallic communication with a platinum-plate in the interior cylinder, and the copper with a zinc-plate in the outer, the outer cylinder of this second arrangement may be filled like the second with the weak brine, and, in the inner cylinder may be placed the solution of the oxide, which it is intended to reduce by the agency of the hydrogen, which will be slowly evolved upon the surface of the platinum. Metallic manganese and nickel may thus be obtained from their chlorides; and *silicon* from a solution of its fluoride in alcohol. Potassium and sodium, in combination with mercury, may even be obtained in such an apparatus, by placing solutions of their chlorides in contact with that metal.

§ 697. If a solution of muriate of ammonia be placed in the decomposing cell, with mercury in contact with the platinum plate, a curious and striking result is obtained, upon which much hypothetical speculation has been expended. After a few hours, the fluid metal swells up to five or six times its former bulk. Upon removing it from the cell by means of the plate to which it adheres, it is found to be of a buttery consistence, and to possess a dull, silvery, colour, like a metallic amalgam. Upon being immersed in water, it slowly gives off hydrogen; the mercury returns to its former state, and a solution of ammonia is obtained.

§ 698. It has been, and is still, maintained by high authorities, that this product is a real metallic amalgam; and there are two views of the nature of the metal with which the mercury is supposed to be combined. According to the first, nitrogen is supposed to be a body compounded of a metal and oxygen, which is decomposed by the current, the metal being evolved upon the mercury, and combining with it. When thrown into water, it takes oxygen from it, and nitrogen is reproduced, which, with part of the hydrogen, forms ammonia, and another part escapes. Every effort has, however, failed to produce this supposed metal in the separate state.

§ 699. The second view ingeniously supposes that ammonia $(N + 3\,H)$ unites with an additional equivalent of hydrogen to constitute a metal $\overline{(N+3\,H)+H}$, which forms the amalgam with the mercury. This imaginary compound has been named *ammonium;* and this hypothesis has been carried so far as to consider the oxide of ammonium $\overline{N + 4\,H} + O$ to be the base of all the salts of ammonia. As these salts generally contain 1 equivalent of water, their analysis will not contradict the assumption for $\overline{N + 4\,H} + O = (N + 3\,H) + (H + O)$.

This, at present, nunnecessary complication has unfortunately been introduced into some elementary works of first-rate merit, and tends to perplex the minds of students.

§ 700. The phenomenon itself is perfectly explained by the force of adhesion, by which the elasticity of the hydrogen and ammoniacal gases is restrained by the mercury, and which, reacting upon the cohesion of the metal, causes it to expand and increase its volume.

A similar instance of the union of a gaseous body with a liquid metal, is presented to us by silver. This metal, at a white heat, absorbs oxygen in large quantities, without forming a definite chemical compound, and gives it off when it solidifies. Its bulk contracts to such an amount as often, from the sudden compression of the gas, to throw particles of the metal out of the crucible.

§ 701. In the phenomena of current affinity, which we have hitherto considered, the generating and conducting plates have been assumed to be of the same dimensions, but the relative size and position of these surfaces are important circumstances in the arrangement, and greatly influence the amount of force thrown into circulation.

Upon examining a plate of platinum, which has been separated from a zinc plate by a diaphragm, in the manner before described, (§ 688), and surrounded with sulphate of copper, after it has been thrown into action, it will be found that the reduced copper has not only been precipitated upon the face opposed to the zinc, but upon the back surface also; proving that the force which impelled the hydrogen has not only been directed in straight lines between the two plates, but in lines which must have bent round the edges of the conducting plate. It will also be found, upon making the experiment, that, in any pair of plates, the size of the zinc may be reduced to a mere wire without decreasing the effect, provided the dimensions and position of the platinum plate remain unaltered. This spread and direction of the force is a highly interesting subject of investigation.

§ 702. If a large silver, or brass, plate, at least a foot square, be placed in a shallow trough and covered with dilute sulphuric acid, to which a portion of sulphate of copper has been added, and an amalgamated zinc wire, of about one-eighth inch diameter, be allowed to rest by one of its ends upon its centre, the instant the two metals come into contact, a circular spot of reduced copper will be thrown down, and rapidly spread itself in such a way that, in a few hours, a well-defined circle of six inches in diameter will be formed. When the experiment is made by enclosing the zinc wire in a glass tube, the lower end of which is covered with bladder and filled with the dilute acid, so as to prevent the immediate contact with the plate, provided a good metallic contact be made by means of a conducting wire with any other part, the precipitation will still proceed from the point immediately under the wire as from a centre.

Again.—If a small piece of zinc, whose length is somewhat greater than its width, be soldered to the centre of a silver plate of about six inches square, and it be placed perpendicularly in a jar, and covered with the solution of copper in acidulated water, the copper will immediately precipitate itself upon the silver in the form of an oval surrounding the zinc, and gradually extending itself equally on all sides, will, in a few hours, reach the edge of the plate. It will then make its appearance upon the opposite surface, till, ultimately, both sides are coated; the deposition, however, decreasing in thickness, as it recedes from the central zinc.

§ 703. This effect of a small generating surface upon a large conducting one, is strikingly contrasted with the result, when we reverse the circumstances of the arrangement; for, by causing a platinum wire to rest by one end upon a large surface of amalgamated zinc, covered with the acidulated water, hydrogen, of course, escapes from the former metal; but the oxidation of the latter is so limited that a hole is eaten through it at the point of contact.

§ 704. This influence was most ingeniously applied by Sir Humphry Davy, to the prevention of that corrosion of the copper sheathing of ships, which takes place in salt water to such an extent as to be a matter of national concern. By placing masses of zinc or cast-iron upon the ships' bows, and near the stern, in contact with the copper, and exposing a surface of not more than $\frac{1}{150}$th of that of the latter metal, it was completely protected. Unfortunately, however, along with the hydrogen, which was thus diffused over the surface of the copper, a quantity of the earthy bases of the saline compounds which are contained in sea water, were determined to the same surface, and formed a crust, which is most favourable to the adhesion of weeds, and of certain marine animals, which impede the sailing of a ship. On this account, the use of the protectors was given up; but probably too hastily, for, by insulating the generating metal, it would be easy to contrive the means of bringing it into activity, by a temporary connexion, at such times only as its influence could not fail of being beneficial.

§ 705. From the disposition which is manifested by the force, in these experiments, to spread itself equally in all directions from an active centre, it might be concluded, that the most simple and perfect combination of this kind would probably consist of a solid sphere (or rather active point) of a generating metal, surrounded by a hollow sphere of an inactive conducting metal, with an intervening liquid, capable of decomposition by the former, and not by the latter; the circuit being completed by a conducting wire properly disposed for connecting the two metals. The properties of such a circuit may be submitted to experimental examination, by means of the following arrangement.

Two hollow hemispheres of brass are fitted together water-tight, by means of exterior flanges half an inch wide, and a collar of leather, and thus form a sphere, the interior diameter of which is 9¼ inches; consequently exposing a surface of about 268.8 square inches. The lower hemisphere is fitted into a frame carrying buttons by which the upper can be securely wedged down upon it; and underneath these is a small cock, by which any liquid in the interior may be drawn off. The upper part of the upper hemisphere terminates in a tube of about one inch in length, forming an opening through which a membranous bag may be introduced, and from which it may be suspended. This bag is then charged with a mixture of sulphuric acid and water, consisting of one measure of the former and eight of the latter, and the unoccupied part of the sphere is filled with the same mixture, saturated with sulphate of copper.

§ 706. When a small sphere of amalgamated zinc, of one inch diameter (and exposing, therefore, a surface of 3.14 square inches), is suspended by means of a well-varnished copper wire in the centre of the sphere so arranged, and the other extremity of the wire is connected by the intervention of a galvanometer with the outside of the upper hemisphere, the needle will be deflected to a certain amount, say 60°, and will remain quite steady for many hours. If the apparatus be then opened and examined, the upper hemisphere will be found coated with a beautiful deposition of pink copper. The lower hemisphere, which was cut off from metallic communication with the upper by the collar of leather, will have no such precipitate upon it.

§ 707. If the sphere be then put together again, and charged as before, and the circuit be closed as in the last instance, with the upper hemisphere, the deviation of the needle will of course be the same. If the connexion be then broken with the upper hemisphere, and made with the lower, the deviation will still be 60°, and when connexion is made at the same time with both hemispheres, the position of the needle will not alter. If, while in this state, either wire be lifted singly from its connexion with either hemisphere, the needle will remain perfectly steady.

§ 708. Upon bringing the conducting wire of the lower hemisphere into direct communication with that of the zinc ball, while the wire of the upper hemisphere is connected as before with the galvanometer, or *vice versa*, the needle will only recede to 40°. From this it appears that, although the whole amount of the force originating at the zinc is capable of passing off by means of either hemisphere singly, when both passages are open, it distributes itself between the two, notwithstanding an additional resistance is interposed in one by the addition of the galvanometer. Extra contacts with different parts of the two hemispheres make no difference in any of these results.

§ 709. When the sphere is opened, after it has been in action for some time with both the hemispheres connected, an equal coating of copper is found equally diffused over each. There will be no greater accumulation of the precipitate about the points with which the conducting wires were brought into immediate contact, and towards which the force diffused over the sphere must have converged, than at any other point; proving that the force which must have diverged from the centre equally through the liquid, could only have drawn towards the conducting wires in the conducting sphere itself.

If two zinc balls be placed in the position of the single one, or if a rod of the same amalgamated metal, six inches in length and half an inch in diameter, be substituted for it, the increase of the generating surface will make very little difference in the amount of the circulating force.

§ 710. If, when both the hemispheres are in metallic communication, the position of the zinc ball within be varied, it will be found that, whatever be the change, no difference in the result will ensue. Whether it be placed at the bottom of the membrane almost in contact with the sphere, or drawn up nearly to the top, or again placed in the centre, no appreciable alteration in the galvanometer will be found.

§ 711. The diffusion of the precipitated copper is, however, very much influenced by the position of the ball; when near the top or the bottom it is thrown down in a compact layer on the segment immediately in its vicinity, and becomes thinner and thinner over the more remote parts of the sphere. To observe this effect with the greatest distinctness, the action in each case must not be allowed to continue more than ten or fifteen minutes; for the deposition becomes compact in every part in a longer time, when it is not so easy to judge of the different degrees of thickness.

§ 712. If we imagine a luminous point placed in the same way within an opaque hollow sphere, we know that in every position its intensity would remain the same, but only from the centre would its light be equally diffused; and when approximated towards any part of the surface, that part would be more strongly illuminated than the others from which it had receded.

Hence it is probable that the force generated in these combinations, where it is limited in its diffusion by the concave surfaces of spherical forms, follows in its action the law of *radiant forces*, that is, its intensity is as the inverse square of the distance (§ 27); but we know at the same time that it is not a *simple* radiant force, like that of gravity, but a molecular force, propagated from particle to particle of matter, and possibly modified by other forces with which the same particles may be endowed.

We have already found the force bending its way round the edges of a conducting plate, as indicated by the copper precipitated upon its posterior surface, in a way which cannot be explained by the hypotheses of simple radiation. This action may receive some further elucidation from the following experiments:—

§ 713. A circular plate of copper, of the same diameter as the brass sphere, was placed in a pan, and covered with a depth of 4½ inches of the acid solution of copper. A wire, well covered with varnish, projected from it, by which it was connected with a calorific galvanometer, the other extremity of which was in connexion with a zinc ball of 1⅛ inch diameter, placed in a membranous bag of acid over the centre of the plate. When the ball was just immersed below the general level of the solution, the instrument marked 82°, when in the middle 92°, and at the bottom, close to the plate, 105°.

After these experiments the copper was found diffused over both sides of the plate, but did not quite extend to the centre of the under side.

§ 714. The upper surface of the plate having been thoroughly covered with lac-varnish, the experiment was repeated with the following results:—

Ball at top	69°
„ middle . . .	75°
„ bottom . . .	70°

The precipitated copper was here found deposited upon the under side, in a ring about two inches in breadth from the edge, and there was very little in the centre of the plate and none upon the upper surface.

The under surface was then covered with the varnish, and the clean upper surface exposed, with the following results:—

Ball at top	73°
„ middle	83°
„ bottom	93°

§ 715. Hence it appears that the under surface, which by itself is capable of sustaining an action from the ball in the centre of the solution nearly as great as the upper surface, when combined with the latter, adds no more than 10°, or about one-eighth, to its efficiency. It appears also that, whereas with the upper surface the action increases in some inverse ratio of the distance of the generating from the conducting surface, with the under surface there is a maximum point, on both sides of which it decreases. This point is doubtless dependant upon the angle at which the force, which radiates (as it were) from the ball, meets the edge of the plate.

§ 716. Next in simplicity to the arrangement of the concentric spheres of generating and conducting metals, is that of a rod of zinc within a cylinder of copper. When the latter is six inches in height, and eleven inches in circumference, and the rod of the former, of the same height and half an inch in diameter, is placed in a membranous cell in its interior, the whole being charged with acid and solution of copper as before, the amount of circulating force is the same as in the sphere before described. When a ball of one inch diameter was placed in the centre of the cylinder as a substitute for the rod, the amount was only decreased one-twelfth, and two such balls were fully equal to the rod. This arrangement is of course much more convenient for the purposes of experiment than the former.

§ 717. When these dispositions are reversed so that the sphere or the cylinder may be of amalgamated zinc, and the interior ball, or rod, of copper, the membranous cell being filled with the solution of copper, and the diluted acid next to the surface of the zinc, the amount of force is reduced to one-half; but no change is produced upon varying the position of the conducting ball within the sphere, so that the same law of distance is maintained as before.

§ 718. Now, it is curious to observe how chemical affinity in all these experiments waits upon the conducting and collecting power. The strong attraction of zinc for oxygen is held in complete check till a passage is open for the circulation of the force and the transfer of the hydrogen; and its efficiency is entirely dependant upon the facility of the passage; for it must not be forgotten that a double effect indicated by the galvanometer implies a double oxidation of the zinc, and a double reduction of the copper, in the same time.

§ 719. In all the arrangements which we have described, one portion of the circuit has consisted of a liquid compound, opposing the transmission of the force in proportion to the thickness of the stratum which it has to traverse, and the other of a metallic conductor, the opposition of which is scarcely appreciable in the comparison; let us now inquire whether the current may not be made to travel, both from its source and back again, by liquid conduction; whether a second portion of a compound liquid might not be substituted for the conducting wire in closing the circuit.

If we connect two cells together in such a way that the zinc plate of one may be in metallic communication with the zinc plate of the other, and the platinum with the platinum, it is clear that each generating plate would tend to form a current; and the two, as regards a circuit, would be in opposite directions. The force which would be transferred from the zinc to the platinum of the first, can only return by passing from the platinum to the zinc of the second, and is balanced by the tendency of an equal force to pass from the zinc to the platinum of the same cell (144).

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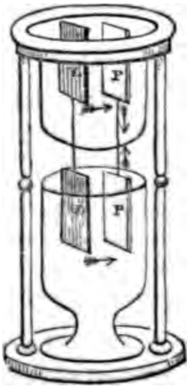
(144) The annexed sketch represents two cells placed one above the other, the zinc plate of the lower being a continuation of that of the upper, and the platinum plates of both being also united together. Under these circumstances a current tends to pass from Z to P in the upper cell, in the direction of the arrow, and to pass down from P to P; but it is met by a counter tendency of an opposite current in the lower cell to pass from Z to P, and to ascend from P to P. These two counter tendencies being exactly equal, neutralize each other, and no current can be established.



§ 720. If we remove all active tendency in one of the cells by the substitution of a second platinum plate for the zinc, still the current of the other will not be able to force its way; for it can only pass from the conducting plate to which it must be consigned by the first portion of liquid, by the decomposition of the second portion of liquid, and the transfer of the force from particle to particle; and the affinity of the oxygen and hydrogen has to be overcome. The divellent force which tends to pass is only equivalent to that which unites the particles of oxygen and hydrogen together, and therefore insufficient to overcome that force in the quiescent state.

§ 721. But if in the second cell we can interpose some liquid compound between the plates whose constituent particles are held together by an affinity of a lower degree of intensity than those of the first liquid, the superior force will overcome the inferior and the current will be established. Thus if one of the cells be charged with acidulated water, and the other with solution of hydriodic acid, or iodide of potassium, the iodine will be disengaged in that cell upon the platinum plate, and the hydrogen and the potassa upon the zinc plate, or the platinum plate which has been substituted for it; in a direction, that is, contrary to that of the natural affinity of the zinc and iodine (145).

The fact may be shown by the addition of a little solution of starch to the charge when the precipitation of the iodine will be very visible. It may be more simply shown by connecting the two conducting wires of an active cell with two platinum plates, and placing between them a fold of white bibulous paper, and another coloured with turmeric, both being moistened by solution of iodide of potassium, and the latter in connexion with the zinc plate, when a yellow spot will be produced upon the white paper by the iodine disengaged, and a brown spot upon the yellow by the potassa (146).

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(145) Referring back to the last figure, if we imagine the upper cell to be charged with acidulated water, and the lower with hydriodic acid, the current from Z to P in the upper cell originating from an affinity of a higher degree of intensity than that which tends to form a current from Z to P in the lower, will force its way against the opposing force, and complete its circuit from Z to P, from P to P, and return from P to Z, and from Z to Z, throwing down the iodine upon P, and evolving its equivalent hydrogen upon Z, contrary to the order of the usual affinity.

(146) The simple apparatus with which Dr. Faraday first made this important experiment is depicted in the next page. A clean plate of zinc,

§ 722. But the amount of force which thus makes its way against the opposing affinity, is far below that which circulates when a metallic path is opened for it, and such obstructing forces are not brought into action; as may be shown by interposing a galvanometer in the circuit, or by the amount of hydrogen disengaged in the generating cell.

§ 723. The affinities which we have thus found to oppose one another in the arrangement of the two cells which we have just described may be made to concur; and to produce very important results. If instead of connecting together the two zinc plates and the two platinum, each zinc be connected with the platinum of the other, the circuit will be complete, and the force will circulate with increased intensity. We may suppose it to commence its course by setting out from the generating plate of the first cell, to traverse the liquid in the way which we have described, and to enter the conducting plate from which it is led by the connecting wire to the generating metal of the second cell. Here a similar current is setting out on its course through the second portion of liquid to the second conducting plate with which it concurs, and the joint impulse passes from particle to particle, and is communicated to the metal by which it returns to the first plate, and the exalted force is equalized throughout the current (147). The number of particles engaged in the generation and the transfer of the current force, and the amount of decomposition in each cell is not increased by this repetition, but the force associated with them is raised in intensity.

Any number of cells may be thus connected by their alternate generating and conducting plates; but no effect will ensue till the platinum of one end of the series is put into communication with

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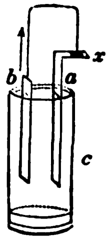
a, was bent to a right angle, and a plate of platinum, *b*, was fastened to a platinum wire, which was bent as in the figure at *x*, a piece of filtering paper, moistened in a solution of iodide of potassium, was placed on the zinc, and was pressed against the end of the platinum wire. When the plates thus arranged were dipped into the vessel, *c*, charged with dilute sulphuric acid, mixed with a little nitric, iodine was immediately thrown down against the platinum wire.



(147) The figure overleaf represents the elementary battery (144) with its plates differently arranged. If we suppose the current to set out from z,

the zinc of the other end: but when the circuit is thus completed, the force will circulate with an intensity proportionate to the number of the cells.

§ 724. The effects of this exalted condition of the force may be shown in different ways. If instead of a cell with a generating and conducting plate arranged in the proper order, one with a pair of inactive platinum plates be interposed in a circuit of ten alternations, the current will be checked, but not stopped in its course; it will pass through the inactive cell with the decomposition of the liquid, the oxygen being evolved upon the plate which occupies the position of the zinc, and the hydrogen upon the opposite plate. If instead of this inactive cell, an active one be introduced with the position of its plates reversed, there will be a tendency in that cell to generate a current in the opposite direction to that of the other cells; but this additional force will be overcome; and so determinate is the direction of the impulse which the elements receive, that hydrogen will be given off upon the surface of the zinc, in opposition to the strong attraction which we know it to possess for oxygen. The current will be able to overcome a number of such obstructions proportionate to the number of concurring cells.

§ 725. The force in this state of intense activity, will also overcome obstacles in a different way. Whatever the quantity may be which is set in circulation in single circuits of large extent, though sufficient to ignite and fuse platinum wire of considerable thickness, the slightest break in the continuity of the conductor will stop the current, but when its energy has been elevated by the

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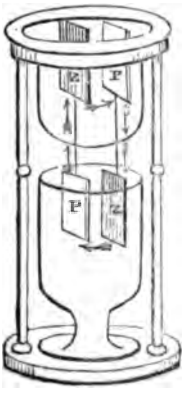

in the upper cell, and to pass in the direction of the arrow to P, it will continue its course from P to Z, in the lower cell, when it will fall in with a current setting out from Z, and passing in the same direction to P. From P, it will return to the upper Z, and the circuit will be complete. Although this action is necessarily described as *progressive*, it is not so in fact; but the exaltation of force which results from this repetition of the circuit takes place in every part of it at the same moment.

repeated impulses of a series, it will project itself through an interval of air in the form of the most dazzling fire, and thus complete its circuit. It will also pass in the same splendid form between two metal or charcoal points in pure water.

§ 726. Any obstruction, however, of whatever kind, reacts upon the whole chain of affinities, and no inequality can possibly exist in different portions of the current, whether in its passage through the liquid, or the solid conductors.

This, as well as some other points of interest, may be well illustrated by a circular arrangement of ten cells, each provided with a pair of platinum and amalgamated zinc plates, which admit of being combined together by conducting wires in different ways. Over each platinum is suspended an inverted graduated glass jar, which is filled with the same dilute acid as the cell, in which the disengaged hydrogen may be received and measured (148).

However accurately it may be endeavoured to assimilate the cells to each other, it will be found that when connected as single circuits, either singly or together, the action of each will differ; but upon connecting them so as to form a single circular series, the inequalities will disappear, and the amount of gas from each in equal times will be equal. When the cells are combined together in pairs, two adjoining platinum plates being connected,

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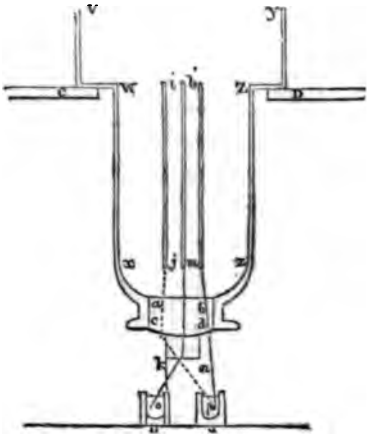
(148) A single cell of this dissected battery is here represented. V W X Z Z Y, is a glass cell, resting by its wide rim in a circular hole in the stand C D. *i j* is a zinc plate, connected by a wire passing through the stopper *a b c d*, with the mercury cup, *o*, on either side of which is a platinum plate, both of which terminate by wires in the mercury cup, *p*. Either of these may be used singly by removing the other. The different connexions of the plates with the associated cells, may easily be made by wires passing between the mercury cups.



The whole arrangement of the ten cells, with the graduated glass jars is exhibited in the next figure. They are placed upon a stand, *a b c d e f*, and two corresponding zinc plates; and the five pairs are afterwards arranged in series by wires, leading from each pair of zinc to the next pair of platinum, the irregularity of the action will again disappear. The arrangement is equivalent to a series of five plates of double the standard size, and the amount of force which circulates is determined by the least efficient pair.

Leaving one pair of cells thus connected, if the others be disunited and recombined with it in single series; the effect will be that of a plate of double size, interposed in a compound circuit with eight single. The gas collected in each of the jars of the double cell, will be exactly half of that in the several jars of the single cells; proving that the double plate is reduced in efficiency to the exact standard of the single plates by its combination with them.

§ 727. In these arrangements every cell is a generating cell, and adds something to the quantity or intensity of the circulating force; and we see that unequal quantities cannot be generated and

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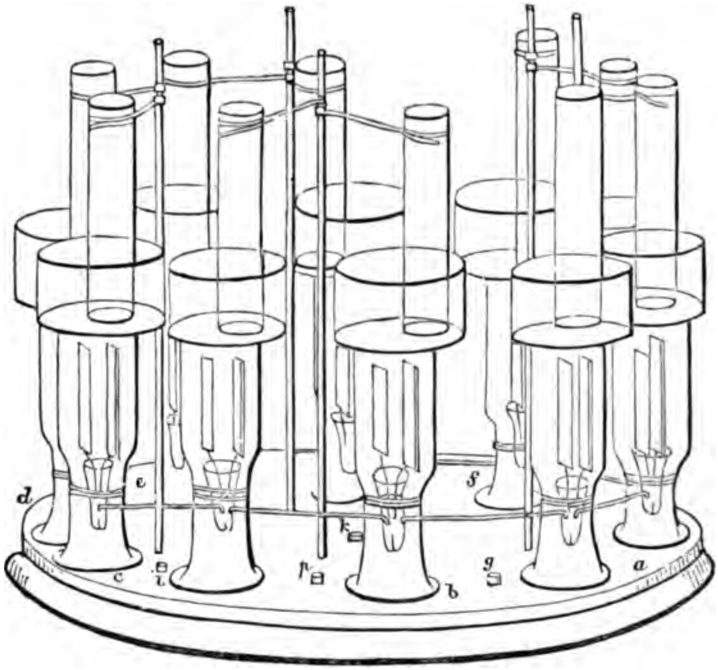
and the connexions between them are easily made and varied by the mercury cups, *i*, *p*, *k*, *g*, &c.



circulate in different parts of the same circuit. The effects of various retarding or opposing cells may be strikingly exemplified by the same apparatus. For this purpose the cells may be connected together in single series, substituting in one a platinum plate for the zinc; and the obstacle will be found to react upon the whole series; the action will be found to be reduced by more than one-third, and the quantities of gas collected from each generating cell will be exactly equal to that collected from the retarding cell. Upon repeating the experiment with a similar change in the next cell, the quantity of hydrogen in all the jars will be equal, but reduced to little more than one-tenth, and the current will be apparently stopped by three retarding cells to seven generating cells.

§ 728. When instead of substituting a platinum for a zinc plate in one of the cells, its position in the series is reversed, the quantity of gas from the nine regular cells declines to about one-fourth. It is, however, remarkable, (and the fact yet remains to be accounted for,) that the hydrogen from the reversed zinc plate will be considerably less than from the platinum of the direct cells, and the oxygen from the corresponding platinum will be the equivalent of the lesser quantity. Whatever the cause of this may be, (and it presents an interesting object of inquiry, in connexion with the reduced quantity of action which we have already found to proceed in a single circuit from a large generating surface to a small conducting one,) it cannot be taken to indicate any inequality in the current, the uniformity of which, throughout its course, has been established as a primary law of the phenomena.

§ 729. When one of the zinc plates is removed from the regular series, and replaced by a platinum plate which has been previously coated with copper by the influence of hydrogen evolved in a circuit, the phenomena are striking and instructive. No gas will at first be evolved from the coppered plate, but it will oxidate, and the progress of the oxidation may be traced by the gradual blackening of its surface. The oxide, again, will be gradually dissolved, and the bright white surface of the platinum will make its appearance, and oxygen gas will begin to rise from it. At that moment the current will receive a check, which will be appreciable in all the air jars.

§ 730. This mode of measuring the amount of current affinity by its chemical effects, has been applied in the construction of instruments, to which the name of Volta-meter has been given.

They consist, in fact, of an independent closed cell, with two platinum plates, from which the gas may be conveniently collected and measured with great accuracy. They may be readily included in any circuit, and, although they check the current in all its parts, they accurately measure the amount which passes through them(149).

§ 731. When a Volta-meter is substituted for one of the ten cells, and the nine have a portion of nitric acid added to their charge, the quantity of hydrogen evolved from their conducting plates is greatly diminished, and becomes irregular; but the quantity of hydrogen indicated by the instrument is nearly treble that of the cells with their original charge.

§ 732. By observations made in this manner, it will be soon found that the action of such a compound circuit is not constant; and that it will gradually decline by a quantity which will be quite appreciable at intervals of five minutes. By breaking the connexion for a short period, its energy will be partially recovered, but will again decline as the action is renewed. Upon allowing the charge nearly to exhaust itself, it will be seen that the platinum plates have become incrusted with metallic zinc, originating, doubtless, from the oxide of zinc formed at the generating plates, and reduced by adhering hydrogen at the conducting plates. Its varying quantity and accu

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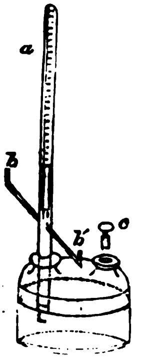
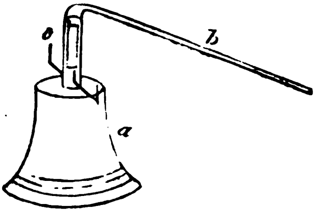


(149) A convenient form of the Volta-meter is here represented. *a* is a straight glass tube, closed at the upper extremity, and graduated into cubic inches and fractional parts. The platinum wires, terminating in two platinum plates within the tube, are fused into its substance, and the tube is fitted by grinding into one mouth of a double-necked bottle, half filled with dilute sulphuric acid. The tube is filled by enclosing the bottle, and when the current passes between the plates, the evolved gases collect in the upper part of the tube, and displace the dilute acid, the stopper *c* being left open. When the tube has been filled with the disengaged gases, the tube may be refilled with the liquid by replacing the stopper, and again inverting the bottle.



Another form of the Volta-meter is here depicted. The gases, as they are disengaged within the tube, filled with the dilute acid, pass by the bent tube *b* under the edge of a graduated jar placed upon the shelf of the water bath.

mulation are amply sufficient to account for the variation and ultimate annihilation of the circulating force; for zinc thus becomes opposed to zinc, and the circuit is destroyed. The momentary breaking of the connexion allows the acid to dissolve off the zinc, which being in contact with the platinum is most favourably disposed for this local action, and upon restoring it, the circulation returns to its first amount, but again speedily declines from the same cause.

§ 733. The apparatus, whose different arrangements we have thus examined, is, in fact, a particular form of the Voltaic battery, that splendid instrument of experimental research which so justly perpetuates the name of Professor Volta, of Pavia. He was led to this grand discovery by a series of experiments, which he undertook, to prove that the agent in Galvani's experiments is common electricity, which he endeavoured to accumulate by a multiplication of his simple circuit.

§ 734. Its first form was that of a pile, in which pairs of zinc and silver discs were placed one above another, each pair being separated from the adjoining by pieces of cloth, rather smaller than the plates, moistened with a solution of common salt (150).

Great care was taken to preserve a regular order in the position of the metals; so that if the zinc were placed below the silver, in the first pair, the same order should be preserved in the others. Another form, which Volta denominated "The Crown of Cups," consisted in a row of small glasses, arranged in a circle, containing dilute sulphuric acid, or a solution of salt, in each of which was placed a plate or wire of silver or copper, and one of zinc, not touching each other, but so connected that the zinc of the first was in contact with the silver of the second, and the zinc of the second

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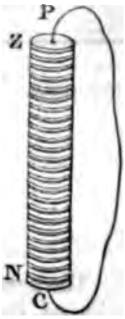
(150) The original Voltaic pile was composed of silver coins and zinc discs of the same size, piled up in the manner here shown, with paper moistened with a saline solution, or a dilute acid, placed between each pair. When the fingers of one hand, well moistened with salt and water, are placed in contact with C, and the fingers of the other hand, with P, a slight shock is felt, and a spark may be perceived upon making contact between the two extremities with a wire or piece of charcoal.



with the silver of the third, and so on throughout the series (151). In this arrangement it could be seen that no current action took place till the extreme wires were brought into contact. Various other forms were gradually introduced by Cruickshank, Babington, and Wollaston, as experience suggested improvements; the principles of which are all explained by the different arrangements which we have described of the *Dissected Battery* (152).

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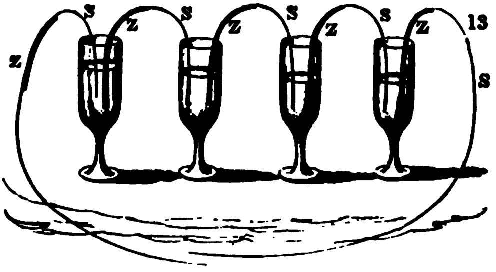
(151) Volta's "Couronne des tasses" is here depicted. Wires of silver and zinc, s and z, are soldered together in pairs, and alternately placed in the glasses containing dilute acid. No action takes place till the extreme wires s and z are brought into communication by means of a metallic wire, when each silver wire is seen to evolve hydrogen.



(152) The inconvenience of the original construction of the pile was in some degree obviated by Mr. Cruickshank, who cemented the pairs of plates into a well-seasoned wooden trough, as in fig. 1. The intervening spaces were filled with the proper liquid for exciting the battery.

Fig. 1.

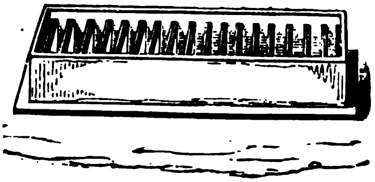
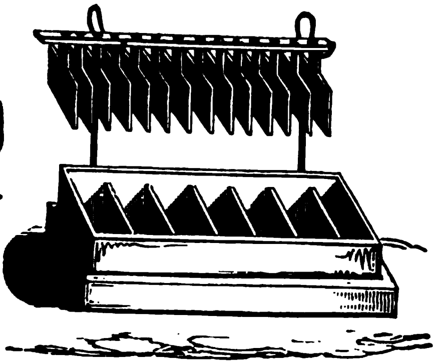


Fig. 2.



The arrangement was still further improved by Dr. Babington, who soldered the plates of copper and zinc together in pairs by one point

§ 735. In Volta's view of the phenomena, the source of electricity was the contact of the dissimilar metals. When two metals, the most dissimilar in regard to their attraction for oxygen, are insulated, and made to touch each other, and again separated, the most oxidizable will be found to be in a state of vitreous excitation, and the least in the opposite state. We have already seen (§ 304), that if a plate of metal be placed upon the cap of a gold-leaf electrometer, and zinc filings be sifted upon it through a copper sieve held by a glass handle, the leaves will diverge with vitreous electricity, and the sieve will be found in a resinous state. With a zinc sieve and copper filings, the electrical changes will be reversed. If we arrange the metals in the following order which is that of their affinity for oxygen, each will become resinous by the contact of that which precedes it, and vitreous by the contact of that which follows it, and the greatest effect will be produced by the contact of the most distant metals of the series:—potassium, zinc, lead, tin, iron, copper, mercury, silver, gold, platinum.

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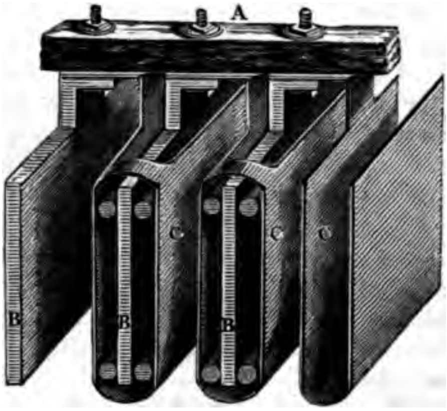
only, and fixed them upon a rod of wood, by which they could be lifted together, in convenient numbers, into or out of a trough of earthenware, divided by partitions into cells for their reception (fig. 2). The fluid may thus be allowed to remain in the trough, while the action may at any time be suspended by raising the plates from the cells, and placing them upon rods fixed for their support.

The improvement of Dr. Wollaston consisted in extending the copper plate so as to oppose it to both surfaces of the zinc, as shown in fig. 3. A represents the bar of wood to which the plates are screwed; B B B the

Fig. 3.



zinc plates, connected, as before, with the copper plates C C, which are doubled over the zinc plates. Contact of the surfaces is prevented by pieces of wood or cork placed between them.

The interposed liquid was regarded by the inventor of the pile merely in the light of an imperfect conductor, which allowed of the accumulation of the electrical fluids, disengaged by the electro-motive power of the metals, by a species of inductive influence.

§ 736. Professor Faraday was the first to prove, by an unambiguous experiment, which we have already described (§ 721), that the contact of dissimilar metals is not necessary to the generation of a Voltaic current, and that the force is exactly proportioned to the amount of chemical action. As the contrary opinion, however, still finds supporters, it may not be superfluous to add another proof of the dependence of the current upon chemical affinity. If a plate of iron and a plate of platinum be each connected with one of the wires of a galvanometer, and immersed into strong nitric acid, no chemical action, as we have already noticed (§ 469), will take place; and, notwithstanding the contact of the dissimilar metals, no effect will be produced upon the instrument; but if a little water be added to the acid, violent action will be established, and the needle will be strongly and permanently deflected. It is not, of course, denied that electricity is developed by the contact of metals; but it is small in quantity, of high intensity, and intermitting in its action; and to generate a current, the contact of a compound liquid with a metal seems to be necessary, as has been before explained.

§ 737. The liquid employed in the voltaic batteries, when it has been desired to excite them to the utmost, has generally been a mixture of sulphuric and nitric acids diluted with water; in which case much local action takes place upon the zinc plates, which contributes nothing to the force which circulates, and which speedily destroys them. Their power, moreover, speedily declines by the deoxidation of the oxide of zinc upon the copper plates, and they are very inconstant in their action.

These defects are obviated in the construction of the *constant battery*, the contrivance of the author, which consists of a series of single circuits constructed upon the principle of a central disposition of the active metal with regard to the conducting surface, as formerly explained (§ 705, &c.)

A cell of this battery consists of a cylinder of copper 3½ inches in diameter, which experience has proved to afford the most advantageous distance between the generating and conducting surfaces, but which may vary in height according to the power which it is wished to obtain. A membranous tube, formed of the gullet of an ox, is hung in the centre by a collar and circular copper plate resting upon a rim placed near the top of the cylinder; and in this is suspended, by a wooden cross bar, a cylindrical rod of amalgamated zinc half an inch in diameter. The cell is charged with a mixture of 8 parts of water and 1 of oil of vitriol which has been saturated with sulphate of copper; and portions of the solid salt are placed upon the upper copper plate, which is perforated like a colander for the purpose of keeping the solution always in a state of saturation. The internal tube is filled with the same acid mixture without the copper. A tube of porous earthenware may be substituted for the membrane with great convenience, but probably with some little loss of power. A number of such cells admit of being connected together very readily into a compound circuit, and will maintain a perfectly equal and steady current for many hours together, with a power far beyond that which can be produced by any other arrangement of a similar quantity of the metals (153).

§ 738. We have noticed that heat generally increases the affinity of substances for each other, as manifested in their local action (§ 651); it has an analogous influence upon affinity in its current state. When a constant battery of 9 cells, which was capable of decomposing water at the rate of 7.5 cubic inches of the mixed gases per 5 minutes, was enclosed in a case to which steam could be admitted, the rate of working gradually increased with the temperature, till at 212° it was very nearly trebled. The greater part of this increased effect is due to the increased energy of the affinity, and not to that of the conducting power only; for when a voltameter, whose temperature was raised to 212°, was included in the

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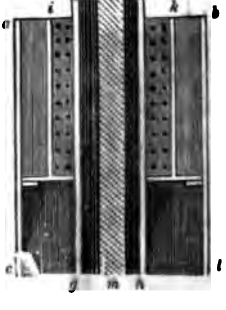

(153) One of the cells of the constant battery is here represented. *a b c d* is a copper cylinder, in which is placed a smaller cylinder of porous earthenware. Upon the upper part of the copper cylinder rests a perforated colander, *i k*, through which the earthenware cylinder passes. *l m* is a cast rod of amalgamated zinc, resting upon the top of the interior cylinder by a cross piece of wood, and forming the axis of the arrangement. The cell is charged by pouring into the earthenware cylinder water acidulated with one-eighth part of its bulk of oil of vitriol, the space between the earthenware tube and the copper being filled with the same acidulated water saturated with sulphate of copper; and solid sulphate of copper being placed in the colander.

cold circuit, the action was only increased from 6.5 cubic inches to 7.5 cubic inches; whereas, when a cold cell was included in a series heated to 212°, the effect fell from 20.5 cubic inches to 9.5 cubic inches.

Changes of atmospheric temperature even have a marked influence upon the working of the voltaic battery, and must not be neglected in nice comparative experiments.

§ 739. How much is dependent upon the force of affinity in the generating metal for one of the elements of the liquid compound, is strikingly shown by contrasting zinc rods in the cells with copper, or even brass. In a battery of 5 cells working at the rate of 5.2 cubic inches of mixed gases per 5 minutes, one copper rod was substituted for a zinc; the whole of the oxygen was absorbed by the copper, but the rate of working was reduced to 2.4 cubic inches in the same interval. A second copper was placed in the room of a second zinc, and the rate declined to 0.6 cubic inches; with a third, it fell to 0.04; and with four copper there was no longer any perceptible decomposition in the volta-meter, but the needle of a galvanometer was deflected 55°. When all the zinc rods were thus gradually replaced by copper, the needle was still deflected 25°.

§ 740. We have hitherto considered the force which is thrown into action in the simple circuit of Galvani, or the compound

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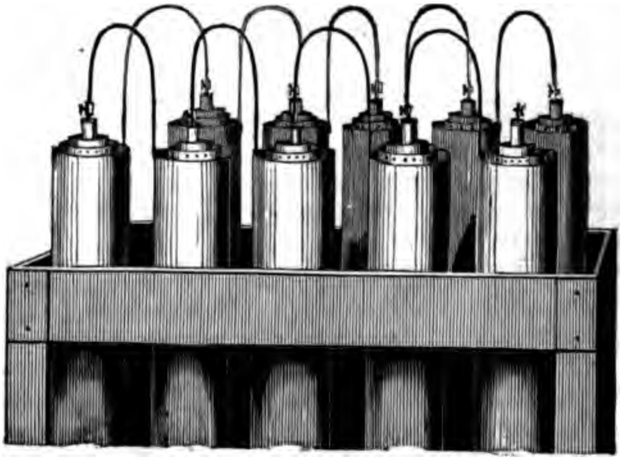
A number of such cells may be connected into a compound circuit, by wires attached to the copper cylinders, and fastened to the zinc by clamps and screws, as shown below.



battery of Volta, as *circulating affinity;* and it is impossible to doubt that the causes which produce the same effects of light and heat, and of chemical decomposition and combination, according to the laws of equivalent proportions, all these effects being synchronous in their manifestation, are identical in their nature, although they are separated in space in one case, and concentrated in a point in the other. It would be impossible, moreover, not to suspect, from a similarity of certain other effects with those of *electricity,* which this spread of the action enables us to develop, that these two forces are also identical, and this, which would be a highly reasonable hypothesis at the point to which we have carried our investigation, will be converted into certainty as we proceed.

§ 741. With this additional view of the connexion of the phenomena, let us cast our eye back upon the ground which we have gone over.

There can be no hesitation in admitting that the force of affinity, both in its local and current condition, is called into action by the contact of the heterogeneous particles of dissimilar bodies: regarded as electricity, the charge and discharge in the first case is limited to the points of contact; while in the second, by a new species of conduction, involving the decomposition of a compound, and the transfer of its elements, the charge is communicated to a distance, and returns to its discharge by another path of appropriate conductors. That one of the active bodies should be a good conductor of electricity, and the other a liquid compound, are essential conditions of the circulation: the first, that the force may readily diffuse itself upon every point of its surface; and the second, that the necessary transfer may take place. In the excitement of electricity by the friction of dissimilar substances, the contact is broken and renewed, with successive particles, by a kind of intermitting action, and by the rapid mechanical separation of the two bodies their charge may be communicated to other bodies in a manner which has been already explained. In its excitement by chemical action fresh articles are also brought into contact in continuous succession, while those which are spent or neutralized are successively removed in combination by the action of concurring forces.

§ 742. In both cases the charge is sustained and communicated by induction, or the polarization of the particles of matter, which must always precede and accompany conduction. When an extensive voltaic series of some hundreds of couples of perfectly clean plates is simply charged with distilled water, (which we have already seen is so bad a conductor of electricity as to allow of a disruptive discharge through it in the form of a spark, § 343 and 781), it is clearly shown that induction takes place in it of precisely the same nature as that which arises from electricity by friction, for each extremity will exhibit a charge of electricity sustained by the induction of the air to surrounding conductors, and which may be manifested by the usual attractions and repulsions, and even sparks, by which we recognise electricity from friction. It will be found that, under these circumstances, the zinc extremity of the battery possesses a vitreous, and the copper extremity a resinous charge.

§ 743. The amount of this effect of high intensity does not at all depend upon the size of the plates, but is proportionate to the number of alternations. A battery constructed of pieces of copper tube ⅜ths of an inch diameter, and 2½ inches long, with a piece of zinc wire of ⅛th of an inch diameter, soldered to each, and turned down into the axis of the next without metallic contact, and consisting of a series of 1024, will be quite equal to a battery of the same number of plates 4 inches square, and capable of producing all the effects which we are about to describe.

A gold-leaf electrometer, placed in connexion with either end, will open out with either electricity, as has just been stated, and if at the same time the electricity of the opposite end be discharged, the leaves will expand still further, as in all analogous cases of common electric charge. When the two ends are connected severally with an insulated slip of gold leaf, upon gradually approaching the two they will attract each other, and a spark will pass between them. By moistening the hands, and touching the two extreme cells, a slight shock is also experienced.

§ 744. These effects may be very much increased by a more advantageous arrangement of the terminal inductric and inducteous surfaces: thus, if one of the ends of the battery be connected with the insulated plate of a condenser, it will instantly become charged, and when the opposite plate is withdrawn, the electrometer will indicate a much higher degree of intensity. The charge may also be sustained through glass, and transferred to the metallic surface of the Leyden battery. If wires proceeding from each extremity of the series be respectively connected with the inner and outer surface of an electrical battery, of not less than 12 square feet of coated surface, it will be charged so rapidly, that sparks may be obtained from it in rapid succession by connecting a fine wire with its outer surface, and successively striking the knob with its other extremity.

The fine point of a penknife, or thin metallic leaves, may thus be burned, phosphorus inflamed, and fulminating powders exploded. No such power is possessed by the voltaic arrangement alone; but it communicates the charge to the battery so instantly, that almost continuous discharges may be procured. The intensity is limited to that which is due to the number of the series, but the extent or surface which may be thus thrown into inductric action is unlimited. When the human body is made the medium of communication between the surfaces of a large battery thus perpetually charged, the rapidly intermitting shock which is received is very unpleasant.

§ 745. The polarity of the voltaic arrangement is also shown by breaking the series at any part, when each portion will exhibit a resinous and vitreous extremity, just as in breaking a magnet each fragment exhibits a north and south pole.

These effects are of course annihilated, by bringing the opposite ends of the series into metallic communication; but no continuous current of any amount takes place when the circuit is closed, on account of the non-conducting power of the pure water which is everywhere interposed. When the extremities are connected with platinum wires, dipping into water even acidulated with sulphuric acid, no decomposition is manifested, however numerous the series may be; but a slight decomposition is shown when a solution of iodide of potassium is made the medium of communication.

§ 746. The electric column of De Luc presents these polar phenomena in a very striking form. It consists of pairs of very thin silver and zinc discs not more than $\frac{5}{8}$ths of an inch in diameter, piled up in regular order, with the intervention of writing-paper, to the number of some thousands. They may, in fact, be formed of strongly gilt paper and zinc foil cut out with a punch, and enclosed in a glass tube fitted with brass caps at each end, and carrying screws, by which they can be pressed together. If the paper be dried artificially, the column will be inactive, but its ordinary hygrometric moisture will be sufficient to throw it into a strong polar state. A series of 2000 or 3000 is sufficient to affect the gold-leaf electrometer, and one of 20,000 will cause pith-balls of $\frac{1}{5}$th of an inch diameter, suspended by threads of 4 inches long, to diverge to the distance of 2 inches and upwards (154). By connecting one extremity of the series with a fine iron wire, and drawing its point lightly over the other extremity, a slight layer of varnish being interposed, a series of minute sparks may be obtained. A Leyden battery may also be charged by it, so as to occasion a disagreeable shock to be felt distinctly in the elbows and shoulders.

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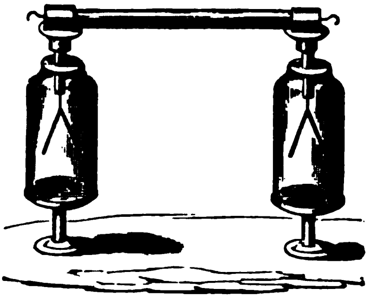
(154) When De Luc's column is placed with each end in connexion with a gold-leaf electrometer as represented in the next page, one of the

This apparatus will retain its power for years if kept in a state of insulation, but loses it if the ends are allowed to be connected together for any length of time. No current, however, is established under these circumstances which can be detected by any chemical decomposition.

§ 747. It may, perhaps, be doubted whether the source of the electric charge of this instrument is the contact of the metals, or the contact of the zinc with the small portion of moisture which is contained in the paper in its common hygrometric state. When the paper has been artificially dried, it is found to be inefficient, as has been already stated, and the zinc becomes slowly corroded in the course of years: but on the other hand the charge is wholly one of intensity, and after its discharge requires an interval of time for its renewal.

§ 748. Now this state of polarity is manifested precisely to the same degree, dependent upon the number of the series, when the voltaic battery is charged with dilute acid instead of pure water. The particles of the liquid, as well as of the solids, are thrown into a similar state of tension, which is only relieved by a good conducting communication between the two extreme poles. The difference of the effects may be well shown by connecting the two poles of such a charged battery with insulated strips of gold leaf, when, upon approximating them as before, they will attract each



instruments will diverge with vitreous, and the other with resinous electricity. When the electricity of either end is discharged by a good conducting communication with the ground, the opposite force is exalted, and the divergence of the leaves increases; and when a metallic communication is made between the two ends, all signs of electricity cease.

other; but instead of the neutralization of the charge by a mere spark, a rush of electricity will burn, and utterly disperse the metal, which is insufficient for its transmission (155). This strong current makes it way through the liquid portion of each cell by a new species of convection, of which the polar arrangement is the antecedent condition.

§ 749. We have upon a former occasion (§ 356) traced the progress of the *carrying discharge* of common electricity: the charged particles which travel may be considered as masses of matter, large or small, compound or simple; and they move towards other masses of matter in which they have produced the opposite state, by induction and polarization of intervening particles. The convection of the voltaic charge can only be effected by the separation of the constituent particles of bodies in certain equivalent proportions, from compounds in which they had been previously combined in the same proportions, and they move also under the influence of the same kind of polarity previously induced. This forced condition never reaches the highest degree of intensity, because it is relieved by the yielding of the compound.

§ 750. The simplest case of this convection is presented to us when the current is led from a series of generating cells into a retarding cell, through which it has to force its passage without the assistance of any concurring affinity. The plates by which it passes into and out of the liquid have been aptly denominated *electrodes*, as being the doors by which the current enters and departs. They may be further conveniently distinguished as the *zincode* and the *platinode*, the former being the plate which occupies the position of the generating plate in the battery, and the latter of the conducting plate. Through the intervening stratum of water, rendered conductive by sulphuric acid, it can only pass by convection and decomposition of the water. For this the particles of oxygen and hydro-

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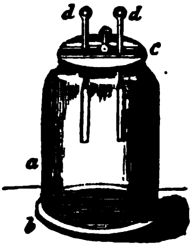

(155) This experiment may be performed with the electrometer here represented. *a* is a glass shade mounted upon a base, *b*. It is covered with a piece of dry varnished wood, *c*, in which the glass tubes, *d d*, slide backwards and forwards, and through which pass wires having gold leaves suspended to their lower extremities. The distance of the gold leaves may be accurately adjusted by a rack and pinion.

gen travel in opposite directions, separating from one and recombining with another throughout the series of previously polarized particles, till the last particle of hydrogen gives up its charge to the platinode and the oxygen to the zincode, and each passes off in its own elastic form. The convection, therefore, cannot be regarded as the transfer of a single force in one direction, but of two forces in opposite directions, and hence Dr. Faraday has happily designated the electric current, whether in metals, or liquids, or air, as "An axis of power having contrary forces, exactly equal in amount, in contrary directions."

§ 751. The polarity of the arrangement, when in a state of action, is well illustrated by interposing between the electrodes a plate of platinum; the side of such a plate which fronts the zincode will give off hydrogen, and the opposite side the equivalent oxygen. If a plate of copper be substituted for the platinum, and sulphate of copper be added to the electrolyte, the first will be coated with fresh precipitated copper, and the second oxidated and dissolved to exactly the same amount. The current which enters by the zincode is conveyed by the electrolyte to the metallic diaphragm, to which it gives up its charge, it re-enters the electrolyte on the other side, and passes on to the platinode, and the opposite faces of the plate exhibit that opposition of forces which characterizes the whole process.

§ 752. The same kind of convection takes place in the generating cells of the battery, but the combination of the disengaged elements at the two electrodes not only removes a strong opposing force, but perpetually renews the heterogeneous contacts by which the current is generated, exalted, and maintained.

§ 753. The inductive influence which precedes and accompanies the current of the voltaic battery, and which we have illustrated by the compound circuit, may also be proved to exist in the single galvanic circuits, which we have previously examined, though not exalted to the same degree of intensity. In them we have been able to trace the course and distribution of the force by the deposition of metallic copper, which marked the limits of its action, and we have found that it not only radiated in straight lines from the generating to the anterior surface of the conducting plate, but that it bent round the edges of the latter, and could, in fact, be wholly sustained by its posterior surface. The same "turning of a corner," has been already adduced as evidence of the polarization of the particles of a dielectric in the instance of common electric induction, (§ 324,) and the bent direction of the force, in the present instance, can only be accounted for on the same principle. There is a complete analogy between the case in which a carrier ball is brought near to the middle of a flat disc of metal, placed upon an excited cylinder of shell-lac without receiving a charge, although one might be obtained all round the edge (fig. 80, p. 221); and that of the deposition of a ring of precipitated copper round the edge of the under surface of a brass plate, under the influence of a ball of zinc, while the centre was free from it (§ 714).

§ 754. We will now turn from the battery itself, and consider the force which is thus generated as an independent power, over which we have complete control, applicable to certain work at any given point, according to laws which we will proceed to investigate; at the same time we must not forget the main fact of circulation, and that the experimental cell, or any other obstacle which we may interpose, constitutes, in reality, a part of the circuit, the resistance of which reacts upon every other cell and conducting portion of the arrangements.

We have already seen (§ 730) in the dissected battery that, when the current is led into a voltameter, or other arrangement in which the oxygen and hydrogen of the decomposed water are both evolved and collected, the check is felt throughout its course, and no more hydrogen is evolved or zinc oxidated in each generating cell, than is equivalent to the hydrogen and oxygen forced asunder in the retarding cell.

The process of resolving a compound body into its elements, or proximate principles, by the voltaic current, has been named *electrolysis*, and substances which are capable of such decomposition are called *electrolytes*.

§ 755. One essential condition of electrolysis is liquidity; the elements of a compound cannot travel when restrained by cohesion; and, with very rare exceptions, compound bodies cannot transmit the current, except by electrolysis.

If one of the electrodes of a powerful battery be separated from the other in water, by a film of ice not more than one-sixteenth of an inch in thickness, there will not be the slightest effect upon a galvanometer included in the circuit; but if a small portion be thawed, so as to form the thinnest possible film of water betweeu the two, the needle will be permanently deflected.

A great variety of both primary and secondary combinations are subject to the same law. On fusing a little chloride of lead in a glass capsule by a spirit-lamp, and introducing into it two platinum wires connected with the poles of the battery, powerful action will take place, the galvanometer will be violently affected, and the chloride rapidly decomposed. On removing the lamp, the instant the chloride solidifies, all current and contemporaneous effects will cease, though the platinum wires may remain enclosed in the chloride not more than the one-sixteenth of an inch apart. Chloride of silver, nitrate of potassa, and chlorate of potassa, act exactly in the same way; and in every case decomposition of the compound takes place when the current passes.

With regard to the substances on which conducting, or rather convective power, is conferred by liquefaction, the degree of power so given is generally very great. Water is that body in which this acquired power is the feeblest; in the various other oxides, chlorides, salts, &c., it is some hundred times greater. A greatly increased conducting power is given to water by the addition of salts, which would seem to be, in a great degree, dependent upon the high conducting power of these bodies when their cohesion has been counteracted; that counteraction being effected in them for the time, not by heat but by solution in water. The addition of other liquids and soluble solids, as sulphuric acid and boracic acid, which by themselves are not capable of electrolysis, and consequently are non-conductors, confer this increased power of convection upon water. Even some elementary substances exalt its conducting power, and a solution of chlorine will convey the current much more readily than pure water.

§ 756. The next point which must arrest our attention is the definite direction which the disengaged elements or principles are forced to take under the influence of the current.

In the cells of the battery the oxygen of the decomposing water, from its natural affinity, must travel from the conducting plate towards the zinc and the hydrogen in the opposite direction; and in the experimental cell which forms part of the circuit, the two gases must move in conformity with these directions; and hence the oxygen will be evolved at the zincode and the hydrogen at the platinode. The elements or principles of any other electrolyte which comes under the government of the current will be subject to the same law of direction, and those elements which, in the order of common affinity have the greatest attraction for the zinc, will take the path of the oxygen, and appear at the zincode, and their associates must travel in the opposite course and escape at the platinode. Thus amongst the elementary substances, chlorine, iodine, bromine, and fluorine, range with oxygen, and the metals with hydrogen; and amongst the proximate principles, cyanogen and acids rank with the former, and alkalies and protoxides generally with the latter.

§ 757. Dr. Faraday, wishing to avoid all reference to any hypotheses with regard to the nature of electrical action, distinguishes these classes of bodies, and certain particulars relating to them, by a nomenclature derived from the direction of the current, which is supposed to pass through the circuit, and which is indicated by the direction of the magnetic needle under the influence of the earth. If in any case of electrolysis we consider the decomposing body placed so that the current passing through it shall be in the direction that the sun appears to move in, or from east to west, then the surfaces at which the electricity is passing into or out of the substance would have an invariable reference to the points of the compass, and exhibit constantly the same relation of powers. He, therefore, calls that towards the east the *anode*, and that towards the west the *cathode*. The anode is that surface of the electrolyte at which, according to the general expression, the current enters, and which is in contact with the zincode, and is where oxygen, chlorine, acids, &c. are evolved. The cathode is that surface of the decomposing body at which the current leaves it, and is in contact with the platinode; it is the place where hydrogen, the metals, alkalies, &c. are evolved. He distinguishes those bodies which go to the *anode* of the decomposing body by calling them *anions*, and those passing to the *cathode*, *cations*. When he has occasion to speak of them together, without distinction, he calls them *ions*. Thus the chloride of lead is an *electrolyte*; and when electrolyzed, evolves the two *ions*, chlorine and lead; the former being an *anion*, and the latter a *cation*.

§ 758. The invariable nature of these relations may be well exhibited by placing several electrolytes in different cells, and including them in one circuit with a battery of sufficient power. Thus, place solutions of chloride of sodium, coloured with indigo; iodide, and bromide of potassium, mixed with starch; and sulphate of soda, coloured with a vegetable blue, in succession in four syphon tubes, reversed, and connect them together, and with the battery, by platinum electrodes; the first will be bleached at the zincode by the evolution of chlorine; the second, coloured blue at the corresponding electrode by free iodine; the third will become deep yellow with the bromine disengaged at the same point; while the indica-

tions of free acid and alkali will be manifested respectively at the zincode and platinode of the fourth (156).

§ 759. The third great point in electrolysis is, that "the chemical action of a current of electricity is always definite, and directly proportionate to the absolute quantity of electricity which circulates." This is not merely true with one substance, as water, but generally with all electrolytic bodies; and further, the results obtained with any one substance do not merely agree amongst themselves, but also with those obtained from other substances; the whole combining together into one series of definite electro-chemical actions, in which the quantities of different kinds of matter acted

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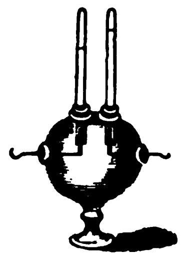
Fig. 1.



(156) Some of the forms of apparatus in which these processes of electrolysis may be conducted, are here represented.

Fig. 1 is a glass vessel with two orifices, each having a tube adapted to it in such a way as to receive the separate gases from the two platinum electrodes which pass into globes filled with acidulated water.

Fig. 2 is a cell made of plates of glass, cemented together and divided into two parts by the temporary diaphragm, *a*, which consists of a small frame of wood, with muslin stretched over it. A separate electrode may be introduced into each side of it, and the products of the decomposition may thus be kept separate for a time and examined.

Fig. 3 exhibits two glasses, connected together by a syphon of large bore, filled with an electrolyte, and two tubes inverted in the glasses and

Fig. 2.

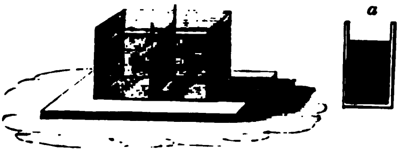
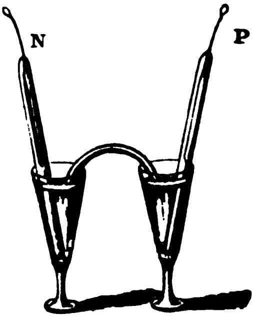


Fig. 3.



filled with the same liquid; into the upper ends of which platinum wires, terminating in long slips of the same metal, are inserted. The opposite products of the decomposition may thus be separately obtained; the convective current passing through the interposed liquid in the syphon.

upon, bear the same proportion to one another as their equivalent numbers.

Thus, when fused proto-chloride of tin, chloride of lead, and water, are placed in succession and decomposed simultaneously by the same electric current, the tin and the chlorine, at the first pair of electrodes, are respectively in the proportion of 58 to 36; the lead and the chlorine at the second as 104 to 36; and the hydrogen and the oxygen at the third as 1 to 8.

§ 760. Variations in the intensity of the current beyond that which is necessary to effect the decomposition of the electrolyte, produce no corresponding variation in the electro-chemical effects. If three Voltameters be so arranged that, after the electric current has passed through one, it may divide into two parts, which, after traversing each one of the remaining instruments, may reunite, the sum of the decomposition in the two latter vessels, will always be equal to the decomposition in the former. The intensity in this case of the divided current cannot be the same as that which it has in its original state, but the two halves of lower intensity produce together the same amount of decomposition as the whole carried into a higher state.

§ 761. As the decompositions dependant upon the current which is urged through the experimental cells are definite, so are the compositions and decompositions which are associated with the current in the battery cells; and it requires the combination of 32 grains of zinc with 8 of oxygen, abstracted from 9 of water, in each of the cells, to generate the current, which is carried forward by the equivalent quantities of the different kinds of matter specified above.

§ 762. From these facts may be drawn the important conclusion that "the quantity of electricity which, being naturally associated with the particles of matter gives them their combining power, is able, when thrown into a current, to separate those particles from their state of combination; or, in other words, that the electricity which is evolved by the decomposition of, and that which decomposes a certain quantity of matter are alike." According to this view, the equivalent weights of bodies are simply those quantities of them which contain equal quantities of electricity, or have naturally equal electric powers; it being the electricity which determines the equivalent number, because it determines the combining force.

§ 763. All compounds are not susceptible of electrolization, even in the liquid state; and there is but one electrolyte composed of the same two elementary ions; in fact, single equivalents alone of elementary ions, and not multiples, can go to the electrodes; and hence only protoxides, proto-chlorides, &c., will transmit the current. This may be probably explained by the necessary uniformity in the actions of the generating and decomposing cells; for as it is the force of single equivalents of oxygen and hydrogen which is first thrown into the current state, so we may conclude that it is by single equivalents alone of other substances it can be transmitted on its course.

To effect the decomposition of a deuto-compound, the current must probably originate from the decomposition and recomposition of a deuto-compound, and the whole circulation must be maintained by compounds of the same order.

All compounds, however, of single proportionals of elements are not decomposable; as chloride of sulphur, proto-chloride of phosphorus, and proto-chloride of carbon.

§ 764. Every electrolyte which can transmit the current can also generate it with any conductor to whose superior affinity it is capable of yielding one of its elements; but few of them would be applicable to the construction of a battery, since for the maintenance of the current, concurring forces are necessary to remove the ions from their respective electrodes, whose influence would otherwise check and terminate the process.

§ 765. The more directly bodies are opposed to each other in chemical affinity, the more ready is their separation from each other in cases of electro-chemical decomposition.

Substances united by weak attractions very rarely conduct, even when liquified, or give up their component parts. Glasses, for instance, which are formed of silica, lime, alkali, and oxide of lead, may be considered as little more than mixtures under the force of adhesion, and many of them appear to be not at all decomposed; but i borate of lead glass, which is a definite chemical compound, be experimented with, it readily yields up its elements.

§ 766. A substance cannot be transferred by the voltaic current beyond the point at which it ceases to find particles with which it may combine; but an acid will experience no difficulty in traversing any portion of alkali, which may be interposed in its passage towards an electrode, or *vice versâ*. If three vessels be placed in a row, and connected together by moistened cotton, the two extreme ones being filled with sulphate of soda, and the centre one with potassa, upon connecting the first with the platinode of the battery, and the last with the zincode, sulphuric acid will be transferred to the latter, notwithstanding it must pass through the intervening alkali from the equivalent soda which is given off at the former. This was formerly regarded as proof of the destruction or suspension of the natural affinities of bodies by the powers of the battery; but that which used to excite wonder and astonishment is, in fact, brought about by that transitory combination which is the essential condition of the transfer.

When it is attempted to pass sulphuric acid through solution of baryta in the same way, sulphate of baryta is precipitated, because from its insolubility it loses that liquid state which is essential to the convection, and no acid reaches the zincode.

If pure water be carefully poured upon a strong solution of sulphate of magnesia, and platinum conductors be so introduced that one may be in contact with the former, and the other with the latter, magnesia will be deposited at the line of contact between the water and the solution; the insoluble base can travel no further, because it meets with no matter with which it can combine; the water then, in fact, becomes the platinode, to which the base yields up the charge, which it is not competent to carry further on its way. The sulphuric acid readily reaches the platinum zincode in the contrary direction, and is there readily detected by its appropriate tests.

§ 767. This experiment is well calculated to demonstrate, that the decompositions of the voltaic battery are not owing, as has been supposed, to any attractive powers possessed by its poles superior to the mutual attraction of the particles separated, for then the magnesia must have completed its course towards this superior force. It is, on the other hand, quite consistent with the view which regards them as produced by an *internal corpuscular action*, exerted according to the direction of the electric current, which is due to a force either *superadded to or giving direction to the ordinary chemical affinity* of the bodies present. It is because the ordinary chemical affinity is relieved, weakened, or partly neutralized in one direction, and strengthened or added to in the opposite direction, that the combining particles have a tendency to pass in contrary directions. Where common affinity fails, current affinity is inoperative.

§ 768. In examining the laws of electro-chemical action, and its consequences, it is very necessary to distinguish between the *primary* and *secondary* character of its decompositions. When a substance under decomposition yields, at the electrodes, those bodies, uncombined and unaltered, which the electric current has separated, then they may be considered as primary results, even though themselves compounds. Thus the oxygen and hydrogen from water are primary results; and so also are the acid and alkali (themselves compound bodies) evolved from sulphate of soda. But, when the substances separated by the current are changed at the electrodes, then they give rise to secondary results; although in many cases, the bodies evolved are elementary.

These *secondary results* occur in two ways; being sometimes due to the mutual action of the evolving substance and the matter of the electrode, and sometimes to its action upon the substances contained in the liquid conductor itself. Thus, when carbon is made the zincode in dilute sulphuric acid, carbonic oxide, and carbonic acid, appear there instead of oxygen; for the latter, acting upon the matter of the electrode, produces these secondary results; or, if the zincode in a solution of nitrate of lead be of platinum, then peroxide of lead appears there, equally a secondary result with the former, but now arising from an action of the oxygen upon the protoxide of lead in the solution. Again: a pure strong solution of ammonia is so bad a conductor of electricity, that it is scarcely more decomposable than pure water; but if sulphate of ammonia be added to it, then decomposition takes place very well, and nitrogen almost pure is evolved at the zincode, and hydrogen at the platinode; but this is a secondary result of the action of the oxygen upon the ammonia in the surrounding liquid. On the other hand, if a strong solution of nitrate of ammonia be decomposed, oxygen appears at the zincode, and hydrogen, with nitrogen, at the platinode. In consequence of the interference of such secondary actions, there is no exceptionable experiment which shows the tendency of nitrogen, under the influence of the electric current, to pass in either direction along its course.

When aqueous solutions of metallic salts are electrolyzed, the metals evolved at the platinode, though elements, are always secondary results, and not immediate consequences, of the decomposing power of the electric current.

§ 769. Chloride of silver furnishes a beautiful instance of the transfer of elements by the concurrence of primary and secondary action. Upon fusing a portion of it upon a glass capsule, and bringing two silver electrodes into contact with it, there is abundance of silver evolved at the platinode, and an equal abundance absorbed at the zincode, for no chlorine escapes, and, by careful management, the platinum may be withdrawn from the fused mass, as the silver is reduced there, until a wire of reduced silver, or rather a bundle of crystals, is produced; at the same time, the silver at the zincode is as rapidly dissolved by the chlorine which seizes upon it, so that the wire has to be continually advanced as it is melted away. The whole experiment includes the action of only two elements, silver and chlorine, and illustrates, in a beautiful manner, their progress in opposite directions, parallel to the electric current, which is for the time giving a uniform direction to their mutual affinities.

§ 770. Many of these secondary results are variable in their proportions, and, by comparison with a Voltameter, may often be shown to want the true definite character which must always characterize real electrolytic results. It has been already shown, that they are brought about by the concurrent action of the force of adhesion; and the amount of the products may often depend upon the extent of surface presented by the electrodes. This circumstance exerts no influence in the case of simple electrolysis. In a comparison of Voltameters, whose platinum electrodes varied from plates of three inches in length by one in breadth, to two inches of a wire one-tenth inch diameter, no difference was found with a battery working at the rate of 2.7 cubic inches per five minutes. At the same time, when the action is sufficiently slow, and the surfaces of the electrodes sufficiently large to insure the complete effects of the secondary actions, the amount must necessarily be in equivalent proportions; and the results may be more liable to be confounded with the primary. Whenever water is present with the electrolyte, and hydrogen does not make its appearance, it may be certain that secondary action has taken place.

§ 771. The influence which the abstraction of the disengaged ions, by secondary action, has upon the amount of the circulating force, has been already noticed in the construction of the constant battery. When the hydrogen is all taken up by sulphate of copper, it has been found to be increased six times. It is placed in a striking point of view by the results of the following experiments. A cylindrical cell of the battery was fitted up with a platinum plate, instead of the zinc rod, within the membranous tube, which was closed at the upper end by a glass tube, bent in a convenient form to deliver the disengaged gas under a receiver. When this cell was charged with dilute sulphuric acid in the interior, and solution of copper in the exterior division, and included in the current, the hydrogen was absorbed, and oxygen evolved to the amount of 7 cubic inches in five minutes, which are equivalent to 21 cubic inches of the mixed gases. When the connexions were reversed, the oxygen was absorbed, and the hydrogen evolved to the amount of 16 cubic inches in the same time; equivalent to 24 cubic inches of the mixed gases. And when the mixed gases were collected in a Voltameter, they amounted to only 17 cubic inches in the same time. Thus the removal of the hydrogen from the sphere of attraction allowed of an increase of action equal to 4 cubic inches, while the increase from the like removal of the oxygen was very nearly double; a difference which is probably referrible to the equivalent combining volumes of the two gases.

§ 772. We have seen reason to infer that bodies may differ in facility of decomposition by the Voltaic current, according to the condition and intensity of their ordinary chemical affinities; for iodide of potassium can be decomposed by the current of a single pair of zinc and platinum plates, immersed in acidulated water, although water resists the same action. Protochloride of tin, when fused, yields to the same low degree of force, yielding prochloride of tin at the anode, and tin at the cathode. Fused chloride of silver is also easily decomposed by the single circuit; chlorine being evolved at the *anode*, and brilliant metallic silver at the *cathode*.

Solution of sulphate of soda, fused nitre, and the fused chloride and iodide of lead, are not decomposable by a single pair of plates excited only by dilute sulphuric acid.

But if a little nitric acid be added to the electrolyte of the generating pair, all the substances which have been before named as giving way, will yield their elements much more readily, and many which before resisted electrolyzation will be decomposed. Thus, solution of sulphate of soda, acted upon in the interstices of litmus and turmeric paper, will yield acid at the *anode*, and alkali at the *cathode;* solution of muriatic acid tinged by indigo, will give evidence of chlorine at the *anode*, and hydrogen at the *cathode*. Solution of nitrate of silver will yield silver at the *cathode*, and fused nitre, iodide and chloride of lead will all be found decomposable by the same means. Thus it appears that the nitric acid not only assists the action so far as to enable a larger *quantity* of the force to circulate by its secondary action upon the hydrogen; but actually exalts its *intensity*.

The following bodies are electrolytic in the order in which they are placed; those which are first being decomposed by the current of lowest intensity:—

Iodide of Potassium (solution),
Chloride of Silver (fused),
Proto-chloride of Tin (fused),
Chloride of Lead (fused),
Iodide of Lead (fused),
Muriatic Acid (solution),
Water, acidulated with sulphuric acid.

§ 773. As different bodies are thus decomposed with very different facilities, and require for their decomposition currents of different intensities, resisting some and giving way to others; so a current may really pass through, and yet not decompose an electrolyte. The quantity, however, is so very small as to require some management to render it evident. By leading a current from a single pair of platinum and amalgamated zinc plates, by platinum electrodes, into a vessel of acidulated water, and thence by a platinum wire, resting by its point upon a piece of filtering paper steeped in solution of iodide of potassium, placed upon another platinum plate, by which the circuit may be completed, it will be found that the current passes by the decomposition of the iodide. Such an apparatus has been found to be still efficient after being in action for twelve days, without the slightest sign of decomposition of the water in the first vessel. Solution of sulphate of soda, substituted for dilute sulphuric acid, in the second vessel, will also conduct a small quantity of the force, sufficient to decompose a minute portion of the iodide, without itself yielding.

This kind of conduction is similar to that which is possessed in the highest perfection by metals, and which appears to be common to all bodies, although it occurs with infinite degrees of difference between the metals and the electrolytes.

When in the apparatus which has just been described, a few drops of nitric acid are added to the electrolyte in the generating cell, evidence is afforded that water is decomposed in the second cell, in small quantities, by bubbles of gas appearing upon the two electrodes. Thus the proof is complete, that the current excited by dilute sulphuric acid, with a little nitric acid, has intensity enough to overcome the chemical affinity exerted between the oxygen and hydrogen of water, whilst that excited by dilute sulphuric acid alone has not sufficient intensity.

§ 774. Having thus explained the great fundamental law of "definite electro-chemical action in direct proportion to the absolute quantity of electricity which passes in a current," we must pause to observe that the electricity of the common electrical machine, notwithstanding the almost instantaneous way in which, from its high intensity, it passes from one point to another during its discharge, must be looked upon as in the current state, and as capable also of producing electrolytic effects in proportion to its quantity. This quantity, however, by which alone it can effect the transfer of the different ions, is almost inconceivably small when compared with that which is generated by the constant action of the voltaic battery. It may be somewhat retarded in its course by causing it to pass through bad conductors, as we have seen (§ 360) by its effects in firing gunpowder, but still, however rapidly the discharges may be made, their course must be always fitful, and unlike the equal flow of the Voltaic current. Notwithstanding this, it may be experimentally shown that voltaic and common electricity have powers of chemical decomposition alike in their nature, and governed by the same law of arrangement.

§ 775. Upon a glass plate place two pieces of tin foil at a distance from each other, and connect one of them by an insulated wire with the vitreous conductor of the electrical machine, and the other with the ground, or with the resinous conductor. Place a piece of platinum wire in metallic communication with each of them by one end, and resting by their mere points upon the glass in the interval. The points are then to be connected together by any electrolyte which it may be intended to experiment upon, and they become the electrodes of the arrangement. When they are made to dip into a large drop of muriatic acid, coloured blue by sulphate of indigo, and the machine is put into action, chlorine will be evolved upon the point connected with the vitreous conductor, and will be shown by its bleaching effects. If a drop of solution of iodide of potassium, mixed with starch, be substituted for the muriatic acid, the evolution of iodine will be indicated at the same point; and when a drop of solution of sulphate of copper is electrolyzed, the evolution of hydrogen will be indicated by the precipitation of the metal at the opposite electrode (157).

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(157) This simple apparatus is represented on the next page. *a* and *b* are two pieces of tin-foil, one of which is connected by an insulated wire, *c*, with the positive conductor of the machine, and the other by the wire, *g*, with the ground or the negative conductor. Two pieces

§ 776. The tension of electricity from friction causes it, however small in quantity, to pass through any length of liquid conductors as fast as it can be produced, and therefore, in relation to quantity, as fast as it could pass through much shorter portions of the same substances. With the voltaic battery the case is very different, and the passing current of electricity suffers serious diminution in any electrolyte by considerable extension of its length. When pieces of litmus and turmeric paper are placed each upon a separate piece of glass, and connected by an insulated string, and moistened with the same solution of sulphate of soda, the terminal points of platinum wire resting upon the papers, alkali and acid appear at the two extremities in their proper places, and no difference will be perceived between this arrangement and one in which the discharge would only take place through a few inches of the same conductors.

§ 777. Metallic communications, or electrodes, are not, in fact, necessary to determine the current in these experiments. If a piece of turmeric paper and a piece of litmus paper, be joined together so as to form one pointed conductor, moistened with sulphate of soda, and be supported on wax between two points, connected with the two conductors of the machine, the vitreous point being opposite thé litmus paper, and the resinous opposite the turmeric, with an interval between each of about half an inch, the evidence of polar decomposition will quickly appear upon working the machine. In this case, the air itself may be said to constitute the electrodes, the particles communicating the charge on one side, and receiving it on the other, after it has performed its electrolytic work.

§ 778. Dr. Faraday remarks, that it is wonderful to observe how small a quantity of a compound body is decomposed by a cer-

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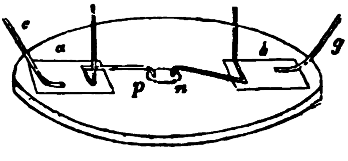
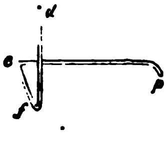
of fine platinum wire, bent as follows, are provided. The part, *d f*, is nearly upright, while the whole rests upon the three points, *p e f*. These are placed as in the first figure, and the points *p* and *n* become the electrodes where the decompositions take place.





tain portion of electricity; and he has made a careful comparison of the electrolytic effects of electricity from friction, and of voltaic electricity, to show what an enormous quantity of the force is naturally associated with the elements of a grain of water, and is required for its decomposition. Two wires, one of platinum and one of zinc, each $\frac{1}{18}$th of an inch in diameter, placed $\frac{5}{16}$ths of an inch apart, and immersed to the depth of $\frac{5}{8}$ths of an inch in acid, consisting of one drop of oil of vitriol and four ounces of distilled water, at a temperature of 60° Fahrenheit, and connected at the other extremities by a copper wire 18 feet long, and $\frac{1}{18}$th of an inch in thickness, yielded as much electricity in little more than three seconds of time, as a Leyden battery exposing a surface of 3500 square inches, charged by 30 turns of a plate-glass machine, 50 inches diameter, in full action. This quantity, though sufficient in its exalted state of tension to have killed a rat or cat if passed at once through its head, as by a flash of lightning, was evolved by the mutual action of so small a portion of the zinc wire and water in contact with it, that the loss of weight sustained by either would be inappreciable by our most delicate instruments. By carrying out this calculation further, it would appear that 800,000 such charges of the Leyden battery would be necessary to supply electricity sufficient to decompose a single grain of water; a quantity which would be equal to a very powerful flash of lightning; but which, in an infinitely lower state of tension, would be supplied, in three minutes and three-quarters, by an electric current capable of keeping a platinum wire $\frac{1}{104}$th of an inch in thickness red hot.

§ 779. The disruptive discharge of the voltaic battery through air is dependant upon precisely the same principles as that of the Leyden battery; but the phenomena are modified by the lower intensity, greater quantity, and perpetual renewal of the force. When passing between two charcoal points, its duration renders it the most splendid source of light which is under the command of art. Rarefaction of the medium through which it passes, either by heat or by mechanical means, produces the same effects as upon the common electric spark from friction. When the poles of a powerful battery are gradually separated after contact, the discharge takes place through an interval which increases with the heating of the air by the ignited charcoal. With the original battery of the Royal Institution of 2000 plates, the discharge passed through four inches of air; and with the constant battery of 70 cells, the flame is much more voluminous, and extends to the distance of one inch.

It would, however, appear that the air is not the only form of matter which is concerned in the phenomena, but that particles of the solid electrodes contribute to the general effect by convection. It is probable that the superior brilliancy of the phenomena with charcoal may be owing to the larger number of its solid particles, which its small cohesion enables it throw off in the process (158).

§ 780. In some experiments with a large battery constructed by Dr. Hare, the platinode was made of plumbago, and the zincode of well-burned charcoal; a most vivid discharge was produced, and fused particles of the plumbago were transported over to the opposite pole, which sensibly increased in length.

In other experiments which were lately made by the author with a constant battery of 70 large cells, a great body of flame was generated which passed through a distance of about an inch, and the charcoal of the zincode invariably presented a cup-shaped cavity, while a considerable protuberance was formed upon the platinode of hardand brilliant carbon with a mammillated appearance. When the zincode was of platinum, and the platinode of charcoal, the latter became studded with globules of fused platinum; and when this arrangement was reversed, a considerable protuberance of carbon was formed upon the platinum platinode.

§ 781. The colour of the light varies with the substances between which the discharge passes. The beautiful effects produced by the deflagration of thin metallic leaves interposed in the course of the discharge are not owing to the combustion of the metals,

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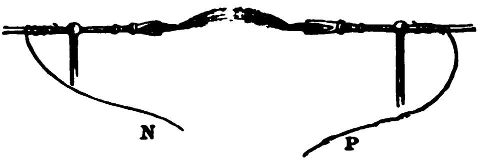
(158) Some notion of the appearance of the voltaic flame, both in the air and in vacuo, may be formed from the annexed sketches. The arched form is owing to the ascensional force of the heated air.



though in some cases increased by this cause, but arise from a dispersion of their particles analogous to that of the more momentary explosion of the Leyden battery. They equally, in both cases, take place in vacuo.

Gold-leaf emits a white light tinged with blue; silver, a beautiful emerald green light; copper, a bluish white light with red sparks; lead, a purple; and zinc, a brilliant white light fringed with red.

The disruptive discharge of the voltaic battery will take place with great brilliancy under the surface of distilled water; some electrolytic effect will at the same time occur, but the greater part of the charge will pass in a brilliant stream of light.

§ 782. It remains now that we trace the passage of the voltaic current through the good-conducting portion of its circuit; and it cannot be doubted that the process depends upon the same condition of particles as that which we described as preceding and accompanying the similar, but momentary, propagation of electricity from friction.

As an intermediate link between electrolytes and conductors, we are presented with a remarkable substance in *sulphuret of silver*. When placed in the circuit with a galvanometer, the needle indicates a feeble conducting power at ordinary temperatures; but on gently warming it, the conducting power rises rapidly with the heat, till at length the galvanometer needle jumps into a fixed position, and the sulphuret, while still in the solid state, is found conducting like a metal. On allowing the heat to fall, the effects are reversed. While hot, the sulphuret conducts sufficiently well to afford a spark like a metal.

§ 783. This effect of heat is in direct contrast with its influence upon metallic bodies, the conducting power of which generally varies with their temperature, and is lower in some inverse ratio as the temperature is higher. If a fine wire of platinum of four or five inches in length be placed in a voltaic circuit, so that the electricity passing through it may heat the whole of it to redness, and the flame of a spirit-lamp be applied to any part of it, so as to raise that part to whiteness, the rest of the wire will instantly become cooled below the point of visible ignition. For the converse of the experiment let the wire be suspended in a loop, and the lower part dipped into water, or cooled by ice, and the other parts will immediately become much hotter, and from a red will rise to a white heat.

The effect of heat upon solid di-electrics is curiously contrasted with its influence upon the conducting power of metals; for if glass be heated it becomes a conductor, and incapable of insulating statical electricity.

§ 784. The metals differ greatly from each other in the resistance which they offer to the passage of the current; and in general it may be stated that those, which are the best conductors of heat, are also the best conductors of electricity: it is therefore remarkable that charcoal, which is one of the worst conductors of heat, is an excellent conductor of electricity. It is not easy to determine the exact differences of the metals by experiments which are free from the intervention of disturbing causes. We have already given (§ 337) a table of the conducting powers of eight metals as determined by Mr. Harris, by the discharge of electricity of friction, upon the hypothesis that they are in inverse proportion to the heating powers. The following Table includes the similar results of the experiments of M. Becquerel upon the same metals with current electricity. It will be seen that they do not very materially differ from the first, although they were obtained by the totally different method of measuring the magnetic powers of the current instead of its calorific effects.

TABLE XXXV. *Electrical Conduction.*

Copper	100.	Platinum	16.4
Gold	93.6	Iron	15.8
Silver	73.6	Tin	15.5
Zinc	28.5	Lead	8.3

In experiments of this kind it is necessary to attend to the purity of the metals; for it has been ascertained, particularly by the experiments of Mr. Harris, that the conducting power of alloys is very different from those of their component metals: an observation which greatly favours the view of conduction which refers it to an action of constituent particles.

§ 785. In consequence of its good conducting power, a much greater length of silver wire of a given diameter will be maintained in a state of incandescence by a constant current, than of platinum or iron; but if a compound wire be made of alternate short lengths of silver and platinum, the latter will become red hot while the former remains cold (159). The charge which passes freely along the silver meets with resistance enough in the platinum to produce ignition. If a platinum wire be passed through a vessel containing water, little of the current is diverted from its course, on account of the bad conducting power of the liquid for electricity of such low intensity; and the consequence is, that it may easily be made to boil by the heat evolved.

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(159) The compound wire may be disposed between the two elec-

The law of conduction in metals has been determined by very accurate experiments to be, that for the same metal the power increases directly as the area of their section, and inversely as their length.

§ 786. It is difficult, if not impossible, to establish anything like a rigorous comparison between the results of two processes so different as those by which conduction is carried on in liquids and solids; but M. Pouillet has determined that the same law is maintained for liquids contained in cylindrical tubes. He has also compared together the conducting power of different saline solutions so placed; the electrodes being formed of the metal, the oxide of which was in solution; but of platinum for pure water. He found that 433 feet of platinum wire 0.006 inch in diameter, were equivalent to a column of saturated solution of sulphate of copper 3¼ feet in length and 0.8 inch in diameter. This result makes the conductibility of the platinum two million and a half times greater than that of the solution.

Then taking the conducting power of a saturated solution of copper at 59°, as the standard of comparison, the power of other solutions he states to be as follows:—

Saturated Solution of Sulphate of Copper	1.
Ditto diluted with 1 volume of Water	0.64
Ditto ditto 2 volumes „	0.44
Ditto ditto 4 volumes „	0.31

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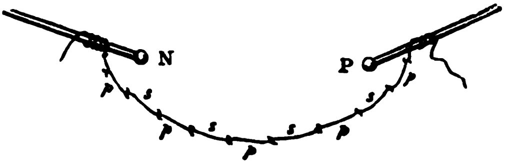
trodes, N and P, as shown in this figure. The platinum links, *p p p p*, become red hot during the passage of the current, while the alternate silver links, *s s s s*, remain dark.



Saturated Solution of Sulphate of Zinc	0.417
Distilled Water	0.0025
Ditto with $\frac{1}{30000}$th Nitric Acid	0.015

§ 787. Now there can be no doubt that the current action of any voltaic circuit is *directly* as the electro-motive force, and *inversely* as the resistances which that force has to overcome; and M. Ohm has shown, that expressing these conditions by the general algebraic formula,—

$$A = \frac{n\,E}{r + n\,r'},$$

we are led, by the various operations which may be performed upon it, to many very important theoretical conclusions, which may be verified by experiment.

A stands for the intensity of action.

E represents the electro-motive force; which is independent of the size of the plates, the conducting power of the electrolyte, and the thickness of its stratum.

n denotes the number of elements in the series.

r' represents the resistance of a single cell of the battery, and is dependant upon three things. 1st. It increases directly as the thickness of the stratum of liquid. 2nd. It decreases directly as the size of the (conducting) plates increases. 3rd. It decreases directly as the conductibility of the liquid increases.

r represents the resistance of the conductors exterior to the cells, including the galvanometer, &c.

§ 788. It would be inconsistent with the objects of this preparatory view to follow out this train of investigation, which will be found to possess great interest for the more advanced student of the science; but we will conclude this part of our subject with some practical results obtained by different combinations of the elementary cells of a large constant battery, measured by the voltameter.

The cylinders were 20 inches in height by 3½ inches in diameter, and the zinc rods were ⅝ths of an inch in diameter. The electrolyte consisted of 8 parts of water and 1 part of oil of vitriol by measure, and in the exterior divisions of the cell was saturated with sulphate of copper. The temperature was about 65°. The duration of each experiment was one minute.

FIRST SET OF EXPERIMENTS.

Number of Cells . . .	1	2	3	4	5	10	15	20
Cubic Inches of Gas	0	Just visible.	1⅛	3⅞	6	12¾	15⅓	17¼

SECOND SET OF EXPERIMENTS.

	All cells direct.	1 inverted.	2 inv.	3 inv.	4 inv.	5 inv.
Cubic Inches .	17½	15½	12¾	10½	8½	5½

	6 inverted.	7 inv.	8 inv.	9 inv.
,,	3½	1⅝	1⅙	Just visible.

THIRD SET OF EXPERIMENTS.

Number of Double Cells . .	5	10
Cubic Inches of Gas .	11	20

FOURTH SET OF EXPERIMENTS.

	5 Triple Cells.	5 Quadruple Cells.
Cubic Inches of Gas .	14½	15⅜

When a series of 5 single cells was connected with a series of 5 double cells and the same voltameter employed, the amount of gas was 14½ cubic inches.

When two series of 5 double cells were each connected with the same voltameter, the amount of gas was 15⅜ cubic inches. Each double series alone gave 11 cubic inches.

From these experiments, it appears that the most advantageous adjustment of active force and resistance is in the series of 10 single cells, and that the largest amount of work which can be derived from 20 cells, is when they are arranged in two series of ten: for,—

Cells.		Cub. In.
10	give	12½
		2
20	...	25

Cells.		Cub. In.
5	give	6
		4
20	...	24

Cells.		Cub. In.
4	give	3⅞
		5
20	...	19⅜

20 in Single Series give 17½ cubic inches.
10 Double Cells give 20 ,,

Cells.		Cub. In.
5 Double	give	11
		2
20	...	22

Cells.		Cub. In.
5 Quadruple	give	15⅜
20	...	15⅜

With a battery of 70 cells in single series, the great powers of which have been already referred to (§ 780), the quantity of decomposition per minute from a voltameter, with the usual charge of acidulated water, was only 17 cubic inches; while with distilled water the passage of a current was scarcely indicated by a few bubbles of gas, which rose from the electrodes.

THERMO-ELECTRICITY.

§ 789. We have seen that, when the electric current meets with obstruction to its course, the equilibrium of heat is disturbed even in good conductors; it might, therefore, have been *a priori* expected that a disturbance in the equal flow of heat would produce an electric current, in such forms of matter as are capable of transmitting it.

We are indebted to Professor Seebeck of Berlin, for the experimental confirmation of this conclusion in 1832, and the discovery of the phenomena of THERMO-ELECTRICITY.

§ 790. If a platinum wire be carefully soldered to the two extremities of a delicate galvanometer, and it be heated at any point remote from the junctions, no disturbance of the electric equilibrium will be produced; from the homogeneous structure of the wire, the heat will flow equally to the right and left of the heated point. But it will be very different if a knot, or a spiral turn, be made in the wire without breaking it: for if the focus of heat be applied to the right of such obstruction, an electrical current will be established from right to left and will be indicated by the needle. This must arise from the unequal rate at which the heat will obviously be propagated on the two sides of the obstructing mass. Wires of copper and silver will act in the same way, only in a very inferior degree. The same effect will be produced if the wire, instead of being continuous, be divided, and each end being twisted into a spiral to increase the surfaces, one be heated red in a spirit lamp, and brought into contact with the other. The deviation of the magnetic needle will indicate as before, that a current is passing from the hotter to the colder point. That these effects do not depend upon any chemical action of the air, is proved by performing the experiment under the surface of well purified oil, under which circumstances the same results will be obtained.

Those metals which possess a decidedly crystalline texture present even more marked electrical phenomena from the unequal propagation of heat in their masses. If a ring, or rectangle, be cast of antimony or bismuth, of the diameter of three or four inches, and of the substance of about the third of an inch, and one half of its surface be kept cool by ice and the other heated, a current of electricity will be immediately established of sufficient power to affect the magnetic needle without the assistance of a coil.

§ 791. These thermo-electric effects, again, are very much increased by combinations of two metals. If a bar of antimony have a copper wire soldered to it, or merely twisted round one of its ends and attached to the other in the form of a loop, when heated at the contact of the metals at one extremity, it will strongly deflect a magnetic needle placed above or below it (160).

It is found that similar circuits may be formed of combinations of other metals, and that they may be ranged in the following order according to their thermo-electric efficiency; the most powerful combination being formed by those metals which are the most distant from each other in the series:—bismuth; platinum; lead; tin; copper, or silver; zinc; iron; antimony. When heated together, the current is found to proceed from those which stand first to the last.

§ 792. There can be little doubt that the specific heat and conducting power of the metals must be concerned in these effects; but in comparing the tables of each, the connexion does not immediately appear. Structure or crystalline arrangement has also much influence upon them. With some combinations, as for example, zinc and silver, the current will go on increasing with the temperature to a certain point, 248°; will then become null and, by increasing the heat, will be re-established in the contrary direction. This singular phenomenon is most probably referrible to a change in the arrangement of the particles of the zinc.

§ 793. The different powers of the currents from different couples of metals, for the same differences of temperature, may be ascertained by forming a compound circuit of all those which it is

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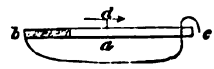
(160) *a* represents a bar of antimony with a piece of copper wire twisted round one end of it, *b*, and looped over the other end, *c*. When heated by the flame of a spirit lamp at the contact of the metals *b*, a magnetic needle placed at *d*, will be deflected.



wished to compare. All the junctions are kept at the temperature of melting ice, except that which is to be thrown into activity, which may be raised by being plunged into hot oil. The mere conducting power of the circuit thus remains the same in every experiment, and the results will be strictly comparable with each other. The following Table exhibits the quantities of the currents for a difference of 36°, of pairs of eight metals differently arranged; the lengths of which were 7.88 inches, and their diameters about two hundredths. The sign + indicates the metal from which the current proceeds.

TABLE XXXVI. *Thermo-Electric Powers of different Metallic Couples.*

	Temp. of Junction.	Deviation of Needle.	Intensity of Currents.
+ – Iron and Tin . . .	68°	36°.50	31°.24
+ – Copper and Platinum . .	68	16.00	8.55
+ – Iron and Copper . .	68	34.50	27.96
+ – Silver and Copper . .	68	4.00	2.
+ – Iron and Silver . . .	68	33.00	26.20
+ – Iron and Platinum . .	68	39.00	36.07
+ – Copper and Tin . . .	68	7.00	3.50
+ – Zinc and Copper . .	68	2.00	1.00
+ – Silver and Gold . . .	68	1.00	0.50

§ 794. Similar circuits may also be formed, according to the experiments of M. Nobili, with substances whose conducting power is lower than that of the metals. He made small cylinders of porcelain clay, of the length of two or three inches and three or four lines in diameter, and wrapped round the ends of each some cotton steeped in a conducting liquid which served to place them in direct communication with the galvanometer. One of the ends was reduced to a point, and after heating it red at a spirit lamp, he pressed it upon the cold extremity of the other cylinder, and a current was established from the hot part of the arrangement towards the cold. This effect is owing to the mutual reaction of two portions of water of different temperatures.

§ 795. The thermo-electric current may be increased by forming a compound circuit, and arranging the pairs of metals in a series of alternations analogous to those of the voltaic pile. If three bars of bismuth with three of antimony placed alternately, so as to form the sides of a hexagon, be soldered together and placed upon two supports in a horizontal position, one of the sides being in the magnetic meridian with a compass-needle below it, upon heating one of the junctions, the needle will be sensibly affected. The deviation will be considerably increased on heating two of the alternate angles of the hexagon; and a still greater deviation will be produced when the heat is applied to the three alternate angles.

In all these combinations, similar effects may be produced by reducing the temperature of one or more of the junctions by the application of ice or other means; and when the action of ice, on one set of the alternate angles, is combined with that of flame on the other set, the effect is still more considerable (161). Upon multiplying still further the number of alternations, it is, however, found that the total effect is inferior to the sum of the effects which the same elements could produce when employed in the formation of simple circuits. This is owing to the low state of intensity of the current which occasions great loss of power, whenever it has to traverse any considerable line of conductors even of the most perfect kind.

§ 796. The thermo-electric pile has lately been applied by Messrs. Nobili and Melloni, as a most delicate and accurate measure of temperature. Thirty-six pairs of bars of bismuth and antimony, packed into a small compass, and having a very delicate galvanometer with two needles attached to them, were found to be so sensible as to be affected by the warmth of the hand at the distance

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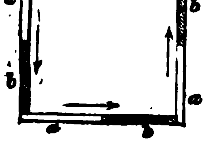
(161) *a a a a* represent four bars of antimony soldered to four bars of bismuth, *b b b b*. If the extremities at *c* be placed in perfect metallic communication, as by the wires of a galvanometer, and the temperature of the junctions be alternately raised and depressed, an electric current will be determined in the direction of the arrows; which will cause the deflection of a magnetic needle placed immediately over, or under, any part of the circuit.



of thirty feet, and an instrument constructed upon this principle, with all the necessary precautions, is applicable to a variety of delicate investigations for which any of the common thermometers would be totally insufficient.

§ 797. The thermo-electric current will occasion convulsions in the limbs of a frog, but is inadequate in its primary state to effect any kind of chemical decomposition.

§ 798. M. Pouillet has compared together the thermo-electric and the hydro-electric currents, by passing the latter through a platinum wire of sufficient length to reduce it to an intensity just sufficient to balance the former. In one of his experiments he found that 590 feet of platinum wire .006 inches in diameter, comprising the resistance of the battery previously determined in this measure, were required to reduce the current from twelve pair of plates with double coppers to an equilibrium with that of one pair of bismuth and copper, in a circuit of 65.6 feet of copper wire of 0.039 inches diameter, with a difference of 76° Fahrenheit of temperature.

By calculating, from subsequent experiments, the relations between the electro-motive forces and the resistance, in these two cases, he ascertained that the hydro-electric current had an intensity 114,000 times greater than that of a single pair of bismuth and copper, produced by a difference between the two junctions of 1.8° Fahrenheit.

§ 799. We are now prepared to examine more accurately the effect which the electric current produces upon the temperature of good conductors, when it passes from one metal into another in the same circuit. We have already seen (§ 785), that when traversing a compound wire of platinum and silver, the alternate links of the former metal become red-hot, whilst those of the latter remain dark and comparatively cool: this effect we ascribed to the difference of the conducting power of the two metals. If a weak current from a single circuit be transmitted through a bar of equal lengths of bismuth and antimony soldered together, from the antimony to the bismuth, heat is evolved at the point of junction, but if in the contrary direction, from the antimony to the bismuth, an absorption of heat, and consequent depression of temperature, will take place. The effects are appreciable by a delicate thermometer, the ball of which may be placed in a hole drilled in the bar at the point of junction, and it will rise in the first case 80° Fahrenheit, and sink in the second 6.5° Fahrenheit. If the bar be laid upon melting snow, and a little water be placed in the cavity made for the thermometer, it will be completely frozen in a few minutes.

§ 800. This production of cold by the voltaic current may be demonstrated also in a striking way by the secondary thermo-electric current which it tends to generate. Let a bar of bismuth 4½ inches long, 0.4 inch square, and a similar bar of antimony be placed across each other at right angles, and mortice half their thicknesses into each other at the place where they cross, and solder them together with tin. On connecting two of their ends with a galvanometer, and sending a current through the others, a deflection of the needle will take place on one side from the current generated by the change of temperature; when the direction of the current is reversed, the needle will be deflected in the contrary direction, proving that an opposite change of temperature has taken place from the reversal of the current. That this secondary current is not due to any diversion of the primary current, may be proved by connecting the two ends of the same bar with the galvanometer, and sending the current through the other bar, when no effect will be produced.

These effects of what may, perhaps, be designated as *electro-thermancy* which we owe to M. Pelltier, are the converse of those of thermo-electricity.

§ 801. There is another well-established and remarkable effect of the heating power of the voltaic current, which is as yet unexplained. When the conducting wires from the two extremities of a powerful battery cross one another, and are brought in contact, upon separating them to a short distance, a flame will appear between the two, and the zincode, or electrode connected with the conducting plate of the battery, will become red-hot, and that connected with the generating metal will remain dark, and comparatively cool. This effect is constant, of whatever metal the conducting wires may be made.

§ 802. The power of fusion by the electrical flame is greatly influenced by this circumstance, and metals laid upon charcoal in connexion with the zincode, melt much more readily when the flame is directed upon them from the platinode, than when their situation is reversed. The constant battery of 70 cells before referred to, completely fused the most refractory metals when thus disposed; and platinum, rhodium, titanium, and iridium, were melted in considerable quantities.

Electro-Magnetism.

§ 803. We must now inquire more particularly into the action and laws of that magnetic force which we have found constantly accompanying the electrical current, however excited, and the measure of which we have already adopted as the measure of its associate force. We are indebted to Professor Œrsted for having laid the foundations of *electro-magnetic* science upon well-devised and convincing experiments. The apparent analogy between the phenomena of electrical and magnetical induction, as well as the uncertain effects of electrical discharges, both natural and artificial, upon the magnetic needle, to which we have already referred (§ 379), early induced philosophers to suspect an intimate connexion between their causes, and various attempts were made to establish such a relation. Nothing, however, satisfactory had been effected up to the time of the Danish Philosopher's researches. The effects of electrical currents and discharges upon the needle had always been sought for at the points where the other effects had been produced, namely, at the poles or interruption of the circuit; but he found them in the uninterrupted current and the closed circuit.

§ 804. When a wire, connecting the generating and conducting plates of a Voltaic battery, is laid in a heap of iron filings, they adhere all around it equally, and not more towards the extreme ends than at any other part, and present the appearance of a closely-compacted layer, instead of that bristled, divergent, arrangement, which characterizes the polar attraction of the ordinary magnet. When the circuit is broken in any part, they immediately fall off under the force of gravity.

The general effect of the conducting wire upon the magnetic needle has already been described (§ 675); the latter is not attracted by either of its poles, as by a magnet, but tends to place itself across the wire; the direction of its poles always having a constant relation to the direction of the Voltaic current (162).

§ 805. The conducting wire produces no effect upon needles

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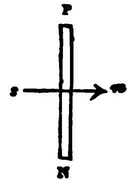
(162) If P N represent the conducting wire, the position of the needle *s n* will depend upon its being above or below the wire. If, when above the wire, the position of the marked end *n*, be to the right, when placed below the wire, the same end will be directed to the left.



of brass or other non-magnetic metal; nor on needles of glass or lac suspended in the same way as the magnetic needle; but its action is freely transmitted through glass, metals, wood, water, or resins; hence it is inferred that the active force is not that which we have distinguished as electrical, but agrees in character with the magnetical.

§ 806. Electro-magnetic effects do not depend upon the intensity of electricity, or the number of the battery series, but solely upon the quantity thrown into circulation, or the efficient size of the conducting surface.

Professor Œrsted early found that a plate of zinc, of 100 square inches, immersed into a corresponding copper vessel containing dilute acid, acted upon the needle at the distance of three feet, but that, when forty such combinations were placed in series, the effect was not increased.

§ 807. The magnetic force of the conducting wire is capable of acting by induction upon soft iron, and of communicating a permanent magnetic polar condition to bars of steel. If needles be attached to the wire in different directions, by fine silver wire, some parallel, others transverse, above and below, they will all become magnetic when the current is transmitted. Those which are parallel to the wire will attract filings in the same way as the wire itself, but those in a transverse direction will exhibit each two poles. All the needles which are placed under the wire will have their poles in one direction, while those which are over it will have their poles in the contrary direction. On breaking the circuit, the needles that were on the wire in a transverse position, will retain their magnetism, whilst those that were parallel to it will be found to lose their force at the same time as the wire itself. The opposite action of the opposite sides of the wire, which we have already found to be indicated by the magnetic needle, is manifest in these permanent effects.

§ 808. These magnetic actions are capable of a high degree of concentration by coiling the wire in such a way as to bring many portions of the same side to bear upon one point. Many hundred needles, fastened in a transverse direction upon the under part of the conducting wire, would instantly be magnetized to the same amount, and in the same direction: but if the wire be twisted in the manner of a cork-screw, so as to form a hollow spiral, a needle placed within it will cross it many times by its several turns, and have the force concentrated upon it, which was previously diffused over the whole number of needles. Such a spiral conformation is denominated a *helix*. It will be obvious, upon a little reflection, that, accordingly as the circumvolutions of such a helix are directed from right to left, or from left to right, or in the manner of a right-handed or left-handed screw, the upper or the under side of the originally-horizontal wire will be turned inwards, and the direction of the accumulated force will vary accordingly. To prevent direct communication between the coils of the wire in experimenting with such an arrangement, the conducting wire should be covered with silk; or it may be twisted round a glass tube, which substances, while they insulate the electric forces, are freely traversed by the magnetic. A steel needle, placed in the axis of such a cylinder, becomes instantly and permanently magnetic, and, as its two poles are oppositely acted upon by the single force of the one side of the wire which is directed upon it, it will place itself directly in the centre, where alone it can be in a state of equilibrium between the attraction and repulsion which impel it in contrary directions. When disturbed from this position, by being pushed nearer to one end, the forces derived from the turns of the wire collectively act with more power upon that pole which is nearest to the middle point of the axis. They will, therefore, prevail over those that urge the more distant pole in the contrary direction, and the magnet will be brought back to its former position in the centre. So powerful is the action of a helix of this description, that, if a small steel bar be placed within it, and supported in a perpendicular position, the moment the connexion is made with the Voltaic battery, it will be seen to start up, and place itself in the axis, remaining suspended in opposition to the force of gravity (163). A heavy body, thus hanging in the air, without any visible support, realizes the situation of the iron coffin of the impostor Mahomet, which is fabled to be thus balanced, without any material connexion and support, between two loadstones.

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(163) Let *p n* represent a conducting wire, in which the electrical current is flowing in the direction of the large dart, and the small darts will then exhibit the direction of the magnetic force.

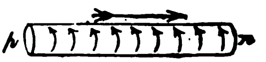

Fig. 1.

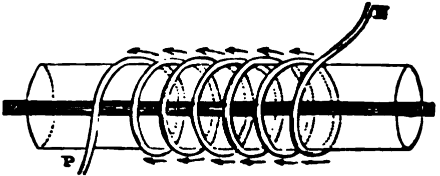

Fig. 2.

In fig. 2, the same wire, p n, is shown coiled in a spiral form round

§ 809. It will now be understood why, in describing the magnetic effect produced by the discharge of the Leyden apparatus, this form of the helix was adopted (§ 379); and in the result which has been described will be seen the confirmation of the opinion that the electricity of the common electrical machine, in the moment of its discharge, must be regarded as in the same current state as that of the Voltaic battery (§ 774). The intensity of the induced magnetism is found to be proportional to the quantity of electricity transmitted through a wire in a given time, whatever the source of that electricity may be, and the magnetizing effects are produced nearly instantaneously.

The concentration of magnetic action, from a wire conducting a current of electricity, may be carried still further by piling the coils of the helix one upon another, in the same direction; five, or six, or more, layers, in succession, may be thus compacted together, and each will add proportionately to the effect. No limits have been determined to this accumulation, provided the intensity of the current be increased in proportion to the increased resistance of the wire by the impulse of a battery series. The effect of the outer coils are transmitted without any diminution from the action of those within.

§ 810. Electro-magnetic induction also takes place temporarily in soft iron, and a very powerful magnet may be obtained by bending a thick cylinder of the best metal into the form of a horse-shoe, and surrounding it with a coil of copper wire, covered with silk or other non-conducting material. When the current of a moderate-sized battery is transmitted through the wire, the iron becomes powerfully magnetic, and will support a very heavy weight by means of a keeper applied to its poles, precisely in the manner of a common horse-shoe magnet. When the electric circuit is broken, all the attractive force ceases, and the weight falls to the ground. If, instead of breaking the connexion with the battery, the electric poles be changed so as to reverse the direction of the current, the poles of the magnet are changed with the utmost rapidity. The weight momentarily separates from them, but is instantly again attracted, and sustained with the same force as before. These

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a glass tube, and it is seen that the magnetism tends the same way in each convolution, and thus acts with concentrated energy upon the needle *n s*, placed in the axis of the arrangement.

effects are much increased by augmenting the number of coils upon the iron, without extending the length of the wire (164). In an experiment made by Professor Henry, of the United States, a horse-shoe of iron was wound with twenty-six stands of copper bell-wire, covered with cotton thread, thirty-one feet long; about eighteen inches of the ends were left projecting, so that twenty-eight feet only of each actually surrounded the iron. The whole length of the coil was, therefore, 728 feet. Each strand was wound on a little less than an inch; in the middle of the horse-shoe it formed three thicknesses of wire, and on the ends it was wound so as to form six thicknesses. With a battery of five feet square, this electro-magnet suspended 2063 pounds, or nearly a ton weight.

§ 811. If the conducting wire of the battery, instead of being coiled into a hollow helix, be bent into a flat spiral, and be attached to one side of a card, through which the central wire passes, and descend in a straight line on the other side, the opposite surfaces will present opposite polarities, and the arrangement will imitate the effects of a magnet whose poles might be supposed to be situated in the centre of each disc. A wire of this form will collect a prodigious quantity of iron filings, which, if the rings are not continued quite to the centre, will arrange themselves in lines passing through the open ring parallel to the axis, and then closing up as radii round the centre (165).

It will be understood that, in all these cases, the direction of the

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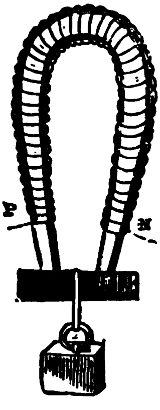
(164) This figure represents the conducting wire, P N, of a Voltaic circuit, covered with silk, to prevent metallic contact, wrapped spirally round a bar of soft iron, bent into the form of a horse-shoe. While the current is passing, the iron is converted by induction from the wire into a magnet exactly resembling the permanent magnet represented in fig. 95, p. 258.



(165) The next figure represents the conducting wire connecting the zinc and copper plates Z and C, which are made to float by a cork in a basin of dilute acid, wound into a flat spiral. A current will then

poles of the arrangements depends, first, upon the direction of the current with reference to the axis of the helix, and, secondly, upon the direction of the circumvolutions which compose it; or, in other words, upon the position of the conducting wire with regard to the generating and conducting metals of the Voltaic combination, and upon the part, upper or lower as the case may be, whose action is concentrated by the spiral folds.

§ 812. We must now return to a more particular examination of the action of the single wire upon the magnetic needle, which is not of the simple nature which at first appears, but which was analyzed by Dr. Faraday with his usual ability. If it be placed in a perpendicular position, and made to approach towards one pole of the needle, the pole will not be simply attracted or repelled, but will make an effort to pass off on one side, in a direction dependant upon the attractive or repulsive power of the pole; but if the wire be continually made to approach the centre of motion by either the one or other side of the needle, the tendency to move in the former direction will first diminish, then become null, and ultimately the motion will be reversed, and the needle will powerfully endeavour to pass in the opposite direction. The opposite extremity of the needle will present similar phenomena in the opposite directions (166). Dr. Faraday drew the conclusion that the direction of the forces

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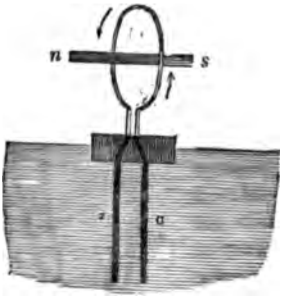
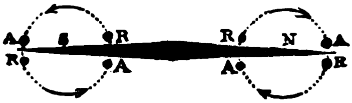
circulate in the direction of the arrows, and each side of the circle will have the opposite properties of two powerful magnetic poles. One end of a magnet, (*n s*,) presented horizontally to its axis, will cause the ring to move towards it, till it reaches its centre, where it will rest in a state of equilibrium. If the magnet be withdrawn, and its poles reversed, and (the ring being held in its first position) it be passed half way through the ring, the latter, when loosed, will, unless placed exactly in the centre, move towards the pole which is nearest to it, and, when clear of the magnet, will be first repelled, and then, turning round, will be attracted, and pass again over the pole, and rest in equilibrio at its centre.



(166) This figure represents horizontal sections of the conducting



was *tangential* to the circumference of the wire; that the pole of the needle is drawn by one force, not in the direction of a radius to its centre, but in that of a line touching its circumference; and that it is repelled by the other force in the opposite direction. In this manner, the northern force acted all round the wire in one direction, and the southern in the opposite. Each pole of the needle, in short, appeared to have a tendency to revolve round the wire in a direction opposite to the other, and, consequently, the wire round the poles. Each pole has the power of acting upon the wire by itself, and not as connected with the opposite pole, and the apparent attractions and repulsions are merely exhibitions of the revolving motions in different parts of their circles.

§ 813. The needle, in its usual mode of suspension, in which the two poles which are oppositely impelled are both subjected to the action of the same part of the wire at the same time, cannot, of course, exhibit these rotatory motions; it rests in a state of equilibrium between the two forces across the wire; but by ingeniously limiting the action of the electricity to one pole, Dr. Faraday succeeded in producing the actual rotation of the pole about the wire, and of the wire about the pole. He immersed a small magnet, perpendicularly, in mercury, confining its lower end to the bottom of the vessel in which it was contained; it thus floated, almost vertically, with one pole above the surface: a wire was then fixed, perpendicularly, so as just to touch the mercury in the neighbourhood of the pole, and when a current of electricity was transmitted through the wire from a Voltaic circuit, the pole immediately began to rotate about the wire. The direction of the rotation depended upon the mutual relation of the pole and current. When the current from the zinc to the copper descended the wire, the marked pole rotated from left to right; the unmarked pole from right to left; and when the current was reversed, the rotation was changed (167). When once the principle

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wire in different positions with regard to the needle, S N, balanced in its centre. They are marked A or R, according as they appear to attract or repel the adjacent poles S and N; and the arrow heads indicate the direction of the circular motions which would result if the poles could be insulated.

(167) The following figure represents an apparatus by which the rotation of the pole of a magnet round the conducting wire, and the corresponding rotation of the wire round the fixed pole may be exhibited. A is a glass vessel, in the bottom of which a hole is drilled, by which a metallic communication is made with the mercury contained in it, with the wire of a

had been illustrated the suspension of both magnet and needle were varied by different experimenters in many different ways; and even the thermo-electric currents excited in two parallelograms of silver and platinum wires, fixed across each other, and heated, at the points of junction of the two metals, by a spirit lamp, were made to rotate under the influence of a magnetic pole.

§ 814. When the electrical current is made to descend through the upper half of the magnet itself, delicately resting upon a point, so as to act exclusively on the pole which is situated in that half, and is then diverted from the lower half, which may be effected by copper wires projecting from the centre and one end, and dipping

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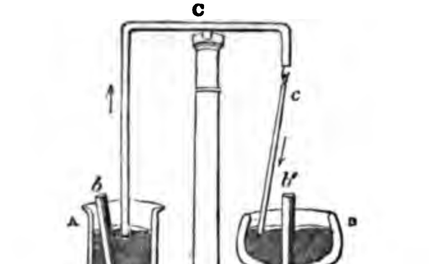
Voltaic circuit *a*; a small cylindrical magnet, *b*, is attached by a thread, fastened to one of its ends, to the bottom of the cup, so that it may float almost upright in the mercury. The Voltaic circuit is completed by means of a wire proceeding from the brass stem *c*, dipping just below the mercury in the cup. When a current is thus established through the wires, and the mercury in the cup, in the direction marked by the arrows,



the pole *b*, which alone will be acted upon, will revolve about the fixed conductor.

B is a similar glass vessel, filled also with mercury, in which the magnet *b'* is fixed to the bottom; one of its poles projecting a little above the surface of the mercury. The wire *c*, which completes the Voltaic circuit, is suspended by a loop, so as freely to move round the pole. When the current is established in the direction of the arrows, the wire commences its revolution. But these rotations may at once be produced by the same current by connecting the wire *a* with the zincode, and *a'* with the platinode, of a Voltaic battery.

into circular grooves filled with mercury, the magnet will rotate with considerable velocity upon its axis.

§ 815. The influence of the pole of a magnet upon electrical currents may be exemplified by liquid as well as by solid conductors. By immersing the two electrodes of a voltaic battery into mercury contained in a shallow basin, a magnet, held either above or below the line of communication, will cause the mercury to revolve round the points from which the currents diverge. Even the flame which is produced by the continuous discharge of a powerful voltaic battery between two charcoal points, is obedient to the same laws; for Sir Humphry Davy found that the arched stream of light, produced by a battery of 2000 plates, was thrown into a rapid rotatory motion by the action of the pole of a magnet placed near it. A very pleasing way of showing this effect is to make a powerful horse-shoe magnet part of the conducting wire of a constant battery of a moderate number of cells; the flame, which may then be drawn from one of its poles, will rotate in one direction, and that from the other in the opposite.

§ 816. The current of electricity, which passes through the cells of the voltaic battery itself, exhibits the same electro-magnetic properties as those in the conducting wire, and a needle is affected by it in the same way. If a double cylinder of copper, of about two and a-half inches diameter, and of the same height, closed at the bottom, so as to be capable of holding dilute acid, be supported by an arch of copper upon a point resting upon one end of a perpendicular magnet, and if a cylinder of zinc, lightly constructed, and dipping into the cell, be supported by another point upon the top of the former, both cylinders will freely turn upon their points. The two together will constitute a single cell of a voltaic battery, and when filled with acid, an electric current will pass from the zinc to the acid, and will ascend from the copper through the pivot back again to the zinc. The zinc, therefore, is in the condition of a conductor, conveying a stream of electricity downwards, and will, consequently, revolve under the influence of the magnetic pole which it surrounds. The copper cylinder, on the contrary, is in the situation of a conductor conveying a current upwards, and will revolve in the contrary direction (168).

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(168) In the annexed diagram, let the circle D represent the section of a wire conducting a voltaic current, and the dark and light arrows the

§ 817. Such a circumferential action and tangential direction of a force was wholly unknown to the time of Dr. Faraday's discovery. All other known forces emanating from a point and exerted upon another point, act in the direction of a line joining these two points; and such is the case with the electric and magnetic actions considered as unconnected.

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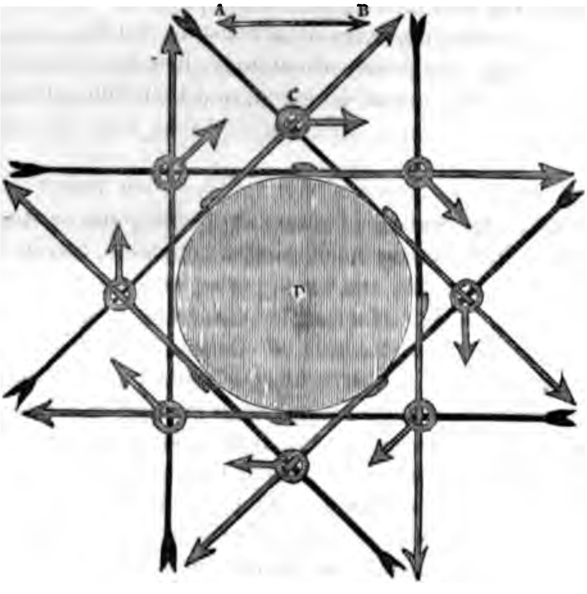
opposite directions of the two tangential forces of the associated magnetism. For distinction sake, let us call the dark arrows the northern force, and the light arrows the southern force. If A B represent a magnetic needle, in which both the forces exist, it is clear that it will be attracted



towards the wire, and, moving in the diagonal of the two oblique forces by which it is simultaneously acted upon, must take up a position of equilibrium directly across the wire. If the small circle (c) represent the pole of a magnet possessing the southern force, it will be repelled at once in a tangential direction *from* the wire by the southern force of the current, and attracted in a tangential direction *towards* it by the opposite northern force; and it will therefore move forward in the direction of the dart attached to it in the diagonal of the two forces. In this manner, if we suppose it carried forward till it falls within the influence of the next pair of forces, the same operation will be repeated, and this tendency simultaneously to approach and recede from the wire in a tangential direction, will produce a movement of rotation

§ 818. Another general fact was ascertained by M. Ampère soon after the discovery of Œrsted, which tends to simplify the problem by rendering the hypothesis probable that magnetic action is, in all cases, referrible to current electricity. When two conducting wires are suspended in such a way as to be capable of moving either towards or from each other at the time that electric currents are passing through them, they mutually attract or repel one another, according as the currents are moving in the same or in opposite directions. It does not matter whether the currents be derived from the same battery or from two; when they flow in the same direction they will manifest a mutual attraction, when in opposite directions a mutual repulsion. This action is variously modified when the relative inclinations and positions of the currents are varied (169).

When a slender steel wire is coiled into a helix, and placed in the voltaic circuit, it will instantly shorten itself, whenever a current is sent through it, owing to this mutual action of the different rings of the coil through which the current passes in the same direction, and it will recover its former dimensions, from its elasticity, the moment the current ceases.

§ 819. M. Ampère assumes the mutual attractions and repulsions of electric currents as the fundamental fact to which, by the help of a particular hypothesis respecting the constitution of

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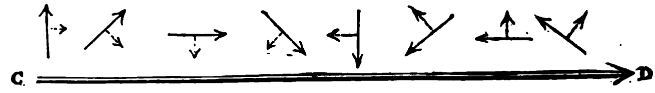
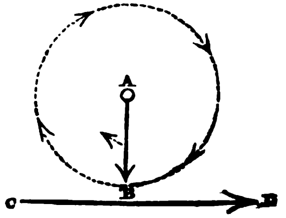
(169) Let C D be an extended current passing from C to D, and the upper lines represent various positions of terminated currents, of which the directions are marked by the terminal arrows. The dotted arrows



will then point out the directions of the resulting motions. It will be seen that when the terminated current is *from* the line of the extended current it is urged to move in the same direction; but when its current is towards the extended current it is urged to move in the contrary direction.



It will at once be perceived that if the motion of the terminated current were restricted to rotation round an axis at one of its extremities, as shown in the annexed figure, the action of the current, C D, would carry the terminated current, A B, round the whole circumference of the circle.

magnets, all the other facts, not only of electro-magnetism but of magnetism also, are reducible. He supposes that all bodies possessing magnetic properties, including the earth itself, derive those properties from currents of electricity continually circulating among the particles of which they are composed, and having, with relation to the axes of these bodies, a uniform direction of revolution, in planes perpendicular to those axes. We have already seen (§ 811,) that the action of conducting wires, rolled into the form of a flat spiral, produces on one side the effects of a marked pole, and on the other of an unmarked pole of a magnet. The actions of a helix at its two extremities, and at some distance beyond them, is similar; and if the two ends of the wire which has formed the helix, be bent back so as to return in a straight course, along the axis till they arrive at the middle point, where they are again bent at right angles, so as to pass out between the coils, it may be freely suspended in various ways, and will completely imitate a magnetic cylinder. Such an *electro-dynamic cylinder*, as M. Ampère has named it, may be substituted in almost every form of experiment for a magnet, whose properties it will possess only so long as a current of voltaic electricity is transmitted through it (170).

§ 820. We formerly (§ 402) referred to the hypothesis of *magnetic elements*, which was adopted to account for the pheno-

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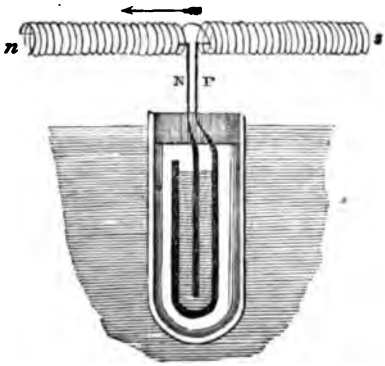
(170) Such an electro-dynamic cylinder is here represented; its ends, after returning through the coil, *n s*, are attached to the wires, N P, of a small voltaic circuit, consisting of a plate of zinc, surrounded by a plate of copper, and floating in a basin of dilute acid, in which it is free to move. Such a spiral will spontaneously place itself in the magnetic meridian under the influence of the earth's magnetism, and will be obedient to another magnet brought to either of its poles.



mena attending the fracture of a magnet, and which considered each particle of magnetized iron as a separate magnet; in like manner M. Ampère's hypothesis regards the electric currents, to which a magnet owes its properties, as circulating round each constituent particle, all of which moving in the same direction will produce a combined effect which is equivalent to that of a circular current flowing uniformly round the circumference. If we regard a needle with its marked end pointing to the north, then the voltaic currents would ascend on the western side, pass from west to east in the upper surface, and descend on the eastern side: they would circulate, that is, in a direction contrary to that of the currents which are supposed to produce the magnetism of the earth.

§ 821. All the principal effects of terrestrial magnetism may be imitated by distributing a wire round the surface of an artificial globe in a spiral direction from the equator to the poles, the two extremities being turned inwards, and brought out at the two axes by which the connexion may be made with the battery. A magnetic needle properly suspended in different situations near such a globe, will arrange itself in positions perfectly analogous to those actually assumed by the dipping needle in corresponding regions of the earth.

The origin of the currents which must, upon Ampère's theory, circulate in the globe from east to west, in planes parallel to the magnetic equator, may possibly be found in the action of the solar rays on successive parts of the torrid zone, producing thermo-electric currents in that direction.

§ 822. The tendency which a magnet and conducting wire have to place themselves at right angles to one another, follows from the same hypothesis, and may be ascribed to the tendency of the transverse currents in the magnet itself and in the conductor to establish a parallelism between them (171).

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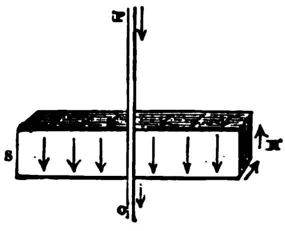
(171) Since the electrical currents in the magnet, N S, must move in planes perpendicular to the axis of the magnet, their magnetic action is transverse to the axis, and tends to bring a straight conducting wire, P Q, into the transverse position represented in the annexed figure. When in this relative position, as the adjacent currents move in the same direction they will attract each other.



The phenomena of revolving motions produced by the tangential force are also easily explained upon the same principles; but we must content ourselves with this brief indication of a theory which has conferred immortal honour upon its inventor.

§ 823. A continued rotation of a different kind from those which we have been hitherto considering, may be produced in a spur-wheel, suspended perpendicularly between the two poles of a horse-shoe magnet, when a voltaic current is transmitted across its diameter by means of some mercury in a groove, into which the wheel is made to dip to allow of freedom of motion. If a mere wire, conducting a current, be suspended in the same situation, it will be attracted or repelled according to the direction of the current, the opposite poles, acting upon opposite sides of the wire, concurring to give it the same direction. In either case it will be thrown out of the mercury, and the circuit being thereby broken, the effect will cease till the wire falls back by its own weight and restores the connexion. The current will then be re-established, and the same influence again exerted. If the wire terminate in a spur-wheel, dipping by its radii into the mercury, as one radius is thrown out of the mercury, another will enter it, and the wheel will revolve with great rapidity. It is not even necessary to divide the wheel into rays in order to produce the effect; for a circular metallic disc will revolve equally well, when it is traversed by an electrical current passing into mercury between the poles of the magnet.

§ 824. The voltaic current may be influenced by the earth's magnetism precisely in the same way as by a permanent magnet, or an electro-dynamic cylinder, and wires delicately suspended have been made to exhibit all the phenomena of attraction, repulsion, direction, and rotation, by its action, although but feeble.

MAGNETO-ELECTRICITY.

§ 825. The phenomena of electro-magnetism are produced by electricity in motion; accumulated electricity, when not in motion, exerts no magnetic effects. Dr. Faraday early felt convinced that "as every electric current is accompanied by a corresponding intensity of magnetic action at right angles to the current, good conductors of electricity, when placed within the sphere of this action, should have a current induced through them, or some sensible effect produced, equivalent in force to such a current." These considerations, with their consequence, the hope of obtaining electricity from ordinary magnetism, stimulated him to investigate the subject experimentally, and he was rewarded by an affirmative answer to the question proposed. He thus became, like Œrsted, the founder of an entirely new branch of natural philosophy.

§ 826. If a wire connecting the two ends of a delicate galvanometer be placed parallel and close to the wire connecting the poles of a voltaic battery, no effect will be produced upon the needle, however powerful the current may be. If the points opposed in the two wires be multiplied by coiling the one, as a helix, within the convolutions of the other coiled in the same way, both being covered with silk to prevent metallic contact, still no effect will be discernible so long as the current is uninterrupted. When, however, the current of the battery is stopped by breaking the circuit, the needle is momentarily deflected, as by a wave of electricity passing in the same direction as that of the main current. Upon allowing the needle to come to a state of rest, and then renewing the contact, a similar impulse will be given to it in the contrary direction. While the current continues, the needle returns to its state of rest, again to be deflected in the first direction by stopping the current. Motion may be accumulated to a considerable amount in the needle, by making and breaking the contacts with the battery in correspondence with its swing.

§ 827. The same effects are produced when, the current being uninterrupted, the conducting wire is made suddenly to approach or recede from the wire of the galvanometer. As the wires approximate, there will be a momentary current induced in the direction contrary to the inducing current; and as the wires recede, an induced current in the same direction as the inducing current.

§ 828. As this *volta-electric induction* is obviously produced by the transverse action of the voltaic current, in one case by the mechanical motion of the wire, and in the other at the moments of generation and annihilation of the current, Dr. Faraday thought that the sudden induction and cessation of the same magnetic force in soft iron, either by the agency of a voltaic current or by that of a common magnet, ought to produce the same results. He constructed a combination of helices upon a hollow cylinder of pasteboard; they consisted of lengths of copper wire, containing altogether 220 feet; four of these were connected end to end, and then with the galvanometer; the other intervening four were also connected end to end, and with the voltaic battery. In this form a slight effect was produced upon the needle by making and breaking contact. But when a soft iron cylinder, seven-eighths of an inch thick and twelve inches long, was introduced into the pasteboard-tube, surrounded by the helices, the induced current affected the galvanometer powerfully. When the iron cylinder was replaced by an equal cylinder of copper, no effect beyond that of the helices alone was produced.

§ 829. Similar effects were then produced by *ordinary magnets.* The hollow helix had all its elementary helices connected with the galvanometer, and the soft iron cylinder having been introduced into its axis, a couple of bar magnets were arranged with their opposite poles in contact, so as to resemble a horse-shoe magnet, and contact was then made between the other poles and the ends of the iron cylinder, by which it was converted for the time into a magnet; by breaking the magnetic contacts, or reversing them, the magnetism of the iron cylinder could be destroyed or reversed at pleasure. Upon making magnetic contact the needle was deflected; continuing the contact, the needle became indifferent, and resumed its first position; on breaking contact it was again deflected, but in the opposite direction to the first effect, and then it again became indifferent. When the magnetic contacts were reversed, the deflections were reversed. The actual contact of the magnets with the soft iron is not essential to the success of these experiments, for their near approximation induces sufficient magnetism in the cylinder to generate the electric current, which affects the needle. The first rise of the magnetic force induces the electric wave in one direction; its sudden decline in the opposite.

Mechanical motion of a permanent magnetic pole in one direction across the coils of the helix, will produce the same effect as the sudden induction of the magnetism in the soft iron, and its motion in the opposite direction will cause a corresponding effect with its annihilation. When the soft iron cylinder is removed from the helix, and one end of a cylindrical magnet thrust into it, the needle is deflected in the same way as if the magnet had been formed by either of the two preceding processes. Being left in, the needle will resume its first position, and then being withdrawn, the needle will be deflected in the opposite direction.

§ 830. On substituting a small hollow helix, formed round a glass tube, for the galvanometer in these experiments, and in roducing a steel needle, it will be converted into a magnet, provided care be taken not to expose it to the opposite action of the reverse current; and if the continuity of the conducting wire be broken at the moment when the secondary electric wave is passing through it, a bright spark may be obtained.

§ 831. The connexion of electro-magnetical and magneto-electrical phenomena may be exhibited in a very striking way, by employing any of the apparatus, by which the rotatory motions of a magnet, or conducting wire, were produced by a current of electricity, to generate electric currents by the mechanical rotations of the magnet or wire. For this purpose, the galvanometer may be substituted for the battery, and when the wire is made to turn round the pole of the magnet, or the pole of the magnet round the wire in one direction, the needle will be deflected to one side; and to the other by the opposite rotation. Nothing can better show that *magneto-electric* is the *converse* of *electro-magnetic* action.

By rotating the wheel, formerly described (§ 823), between the poles of a horse-shoe magnet, a constant current of electricity may be kept up in one direction, and exhibited by connecting one of the wires of the galvanometer with the axis, and the other with the reservoir of mercury, in which the circumference dips and revolves. By turning it in one direction, the current will pass from the axis to the circumference, by turning it in the other, the current will flow from the circumference to the axis (172).

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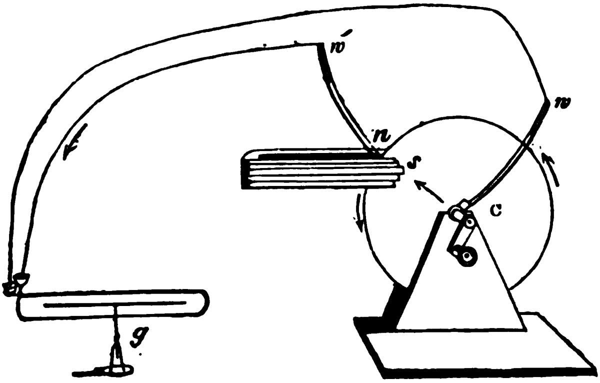
(172) In the annexed figure, c represents a copper disc revolving upon an axis by a winch. *n s* are the poles of a powerful magnet so



§ 832. The general expression of these phenomena may be thus stated:—Whenever a piece of metal is passed, either before a single pole, or between the opposite poles of a magnet, or before electro-magnetic poles, whether ferruginous or not, so as to cut the magnetic curves, (or lines which would be marked out by the spontaneous arrangement of iron-filings,) (§ 581,) electrical currents are produced across the metal transverse to the direction of motion.

§ 833. The same relation exists between the magnetism of the earth and metals in motion, and although the force is small, the induction may be rendered sensible by appropriate arrangements. Dr. Faraday connected the hollow helix, already described, with the galvanometer, by wires eight feet long, and a soft iron cylinder was placed in it, and fixed so as to project equally at both ends. The combined helix and bar were held in the magnetic direction, or line of dip, and were then suddenly inverted, so that the lower end should become the upper, but the whole still correspond to the magnetic direction: the needle was immediately deflected; as it returned to its first position, the helix and bar were again inverted, and by doing this two or three times, making the inversions and vibrations coincide, the needle swung through an arc of 150° or 160°.

These phenomena are the consequence of the inductive magnetic power of the earth, rendering the soft-iron cylinder a temporary magnet with its marked pole downwards: the inversion of position is equivalent to a change of poles, the opposite influence of which is made to coincide with the opposite oscillations of the needle. The rotation of a wheel in such a manner as to cut the terrestrial curves of magnetism is sufficient sensibly to deflect the needle; and even the mere motion, in the same direction, of a long loop of copper wire connecting the two ends of the galvanometer, and passing over, will produce the same effect. Upon moving the

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placed, as to admit of the revolution of the edge of the plate between them. *w w′* are wires, one of which is retained in perfect metallic contact with the axis, and the other with the circumference of the disc at the point immediately passing between the poles. These wires terminate in the galvanometer, *g*. When the copper plate is made to revolve from right to left, a current of electricity is produced in the direction of the arrows, and deflects the galvanometer. If the revolution of the plate, or the poles of the magnet, be reversed, the electric current will move in the opposite direction.

loop in one direction, the needle will pass to one side; and upon moving it back again, the needle will be impelled in the contrary direction: upon repeating these motions in accordance with the vibrations of the needle, it may be made to swing through 90°, or more.

§ 834. After Dr. Faraday's discovery of *volta-electric* and *magneto-electric* induction, many ingenious contrivances were made for exalting the effects and facilitating experiments. The most complete arrangement now in use was the original combination of Mr. Saxton.

A very powerful horse-shoe magnet, formed of numerous steel plates closely applied together, or an electro-magnet of soft iron of the same form, is placed in a horizontal position. An armature of the purest soft iron has each of its ends bent at a right angle, and is mounted in such a way that the surfaces of those ends are directly opposed, and close to the poles of the magnet; in this position it may be made to rotate rapidly in a vertical direction, by means of multiplying wheels and an endless band. Two series of copper wires, covered with silk, are wound round either end of this bar, as compound helices. The extremities of these wires having the same direction, are connected together, and with a circular disc rotating with the armature in a cup of mercury, with which it is therefore in metallic communication in every position of the disc. The other extremities of the wires are united together, and passing without metallic contact through the spindle upon which the apparatus turns, terminate in a slip of copper with two opposite points placed at right angles to the axis. These, in the act of rotation, alternately dip into, and rise above, the mercury in another cup, which may be connected with the first at pleasure by means of a copper wire. By the laws of magnetic induction, the armature becomes a temporary magnet whenever its bent ends are opposite the poles of the magnet, and ceases to be magnetic when they are at right angles to them. The momentary generation and destruction of the magnetic force, which will be oppositely directed in the bar as its opposite ends become opposed to the same poles in the act of rotation, must, by the laws of magneto-electric induction, induce corresponding opposite electric currents in the copper wire if the circuit be complete, by the immersion of the points at the moment of their passage. The points are so arranged, that, standing nearly at right angles to the revolving bar, they just rise from the mercury as its ends become opposed to the poles of the magnet, and the circuit being thus suddenly broken at the moment of the electric wave, the current passes in the form of a brilliant spark (173).

§ 835. By means of this magneto-electrical machine, all the well-known effects of voltaic currents may be very commodiously produced. When the communication is made between the spindle and the revolving disc by means of a fine platinum wire instead of the dipping points, the wire may be maintained at a red heat; although the effect being produced by alternating currents in opposite directions, a kind of pulsation, or intermission of the light, may be discerned. Upon making the communication between the two mercury cups by means of copper cylinders grasped in the hands, a continued painful contraction of the muscles of the arms takes place, which destroys voluntary motion, and, under certain circumstances, is perfectly intolerable. If the currents be transmitted into liquid electrolytes by means of platinum electrodes, they are readily decomposed; but in consequence of the alternate reversal of their

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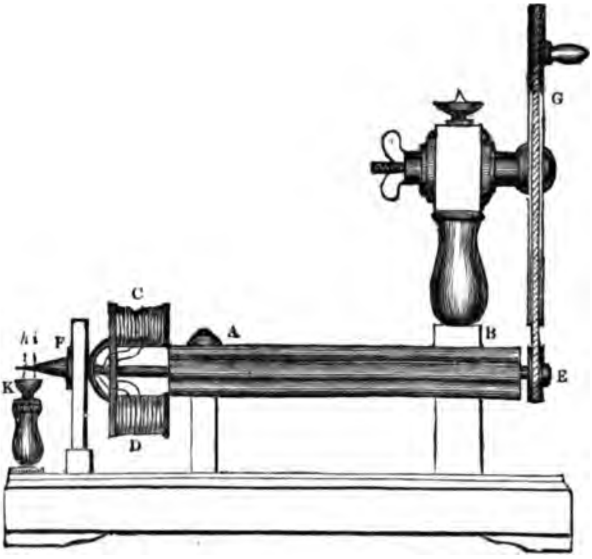
(173) This figure represents a section of Mr. Saxton's magneto-electrical machine. A B is the horse-shoe magnet. C D the armature of soft iron, standing in a transverse direction to the poles of the magnet. E F is the spindle upon which it revolves by means of the multiplying wheels, E G. *h* and *i* are the metallic wheel and points by which connexion is made and broken between the mercury cup, K, and the ends of the coils of wire round the armature, C D.



direction, the *anions* and *cations* are mixed together. This, however, may be avoided, by turning up one of the points of the axis when one of the currents will be cut off, and half the power destroyed, but the usual results of polar decomposition will be obtained. The amount of decomposition in this, as in all other cases, is in proportion to the quantity of electricity which circulates. By means of an electro-magnet and a constant battery, which was capable of decomposing water by the primary current at the rate of eleven cubic inches of the mixed gases per minute, four cubic inches have been obtained in the same time by this secondary force.

§ 836. The mechanism of *electrical induction* has been clearly disclosed by Dr. Faraday, and traced, as we have shown (§ 314), to the action of particles of matter intervening between the inducteous and inductric bodies: he has not been so successful in his endeavours to develop the mode of *magnetic* and *electro-magnetic* induction. All the phenomena dependent upon these actions take place indifferently through all kinds of matter; and bodies contrasted by the extremes of conducting and insulating power, and opposed to each other as strongly as metals, air, and sulphur, show no difference with respect to magnetic forces when placed in their lines of action. As far as experiment has yet gone, the results lead to the conclusion that, notwithstanding the strong analogy which the two series of phenomena present, the transverse inductive force of currents is not transmitted by the intermediate particles in a similar way to static electricity, although both can act at a distance. Dr. Faraday, however, is very far from thinking the question settled; and he is of opinion that " it is fully within the reach of experiment, and offers a high reward to him who will attempt its settlement."

But whatever be the mode in which this electrical condition is induced in a good conductor, there can be no doubt that its particles are thereby thrown into the same state as when conducting a charge from any other source; and this we have already determined (§ 336,) to be a state of electrical polarity, in which the associated forces are freely communicated from one particle to another. There is yet another series of phenomena connected with this state, to which we must refer before we quit this branch of our subject.

§ 837. However large the quantity of electricity may be which is thrown into circulation by a single voltaic circuit, its intensity, as we have seen, must be very low, and it is wholly incapable of effecting its passage by *disruptive discharge*. In consequence of this, when the conducting wire is very short, no spark is visible upon making or breaking contact between the generating and conducting surfaces; or, at most, a very minute one upon the latter occasion. Nevertheless, when the wire is long, a very bright spark is produced upon breaking contact. This spark is greatly increased when the same long wire is coiled up into a helix; and still more when it is wound round an iron-core, so as to constitute an electro-magnet. Under these last circumstances, if the ends of the wire near the battery be grasped by a person with moistened hands, he will experience a considerable shock at the moment of breaking the contact at a point between the place at which it is held and the battery, and the spark will be diminished. If a decomposing apparatus be interposed between the same extremities of the wire, the direct current will pass through the latter so long as the contact with the battery plates is maintained; but upon breaking contact, iodide of potassium will be decomposed in the former, and the situation of the evolved iodine will prove that the decomposition has been effected by a current in an opposite direction to that of the battery current. In this last experiment, a bright spark occurs at the place of disjunction, indicating that only a small part of the extra current passes the decomposing apparatus because of its small conducting power. The most instructive set of results are, however, obtained when a galvanometer is introduced between the extremities of the conducting wire. When contact is then made, a portion of the primary current which passes through the principal wire is diverted through the galvanometric wire, and the needle is deflected. If, while in this stiuation, it be forced back by pins, applied upon opposite sides of its two extremities, to its natural position when uninfluenced by a current, and the battery contact be then broken, it will be strongly deflected in the opposite direction; thus showing, in accordance with the chemical effects, that the extra current followed a course in the cross wires contrary to the one produced by the direct action of the electromotor.

§ 838. It is clear, then, that at the moment of its return to its natural state, a reflex wave of electricity is generated in the conducting wire, which is analogous to that which it is capable of inducing at the same moment in a parallel independent wire. It is generated, also, by the same lateral or magnetic force, and it is increased, like the latter, by the reaction of the temporary magnetism of soft iron in the moment of its cessation, and by the juxtaposition of the coils of a helix.

In fact, if a second and independent wire be placed by the side of the primary conducting wire, as by coiling the two together in one helix, taking care that they may be well insulated, so long as the circuit of the second wire is not complete, the primary wire will give a good spark; but upon completing the secondary circuit, by bringing its ends into metallic contact, the whole of the lateral force will be expended upon it, and little or no spark will appear when the primary circuit is broken. Then, again, if the ends of the second wire should happen to be disconnected at the moment when the battery contact is broken, a spark will there appear instead of occurring at the disjoined extremity of the principal wire. Even the weak current of the thermo-electric circuit (§ 795,) may be made to yield a spark from this secondary action by the assistance of a helix.

§ 839. In the wire of the helix of the magneto-electric machine, these principles of action have an important influence. From the construction of the apparatus, the current is permitted to move in a complete metallic circuit of great length during the first instance of its formation: it gradually rises in strength, and is then suddenly stopped by the breaking of the metallic circuit; and thus great intensity is given by induction to the reverse current which at that moment passes. Different effects are produced by varying the length and diameter of the wire upon the armature. A great length (1500 yards) of fine insulated copper wire will decompose water with the greatest advantage, and give the severest shocks; but a less length (40 yards) of thicker wire will give the largest sparks, and ignite the largest quantity of platinum wire.

§ 840. By a primary coil of thick wire of 120 feet in length, the connexion of which with a voltaic circuit may be rapidly made and broken by a spring pressing upon a toothed wheel and an inducteous coil of finer wire 120 yards long, the ends of which may be grasped by the hands, an electro-dynamic machine may be constructed, the effects of which are utterly intolerable. The continuous shock of this instrument is sufficient to destroy life in a cat, or other animal of the same size, if directed through the head.

§ 841. In the voltaic circuit, the self-induction of the conducting wire generates a current which pervades the cells of the battery itself, as well as its own substance: for if a long wire or coil be connected with a series of cells, not only will the large spark be formed when the circuit is broken at the extremity of that wire, but at any of the short wires of the other cells. The effect upon the electrolyte, from this reaction, has not yet been examined.

§ 842. If we now cast a retrospective glance upon the collective phenomena which have come before us, how wonderful appears the nature of that mysterious force which we can at pleasure call into action by the mutual influence of masses of metal upon each other exerted at a distance, and without diminution of substance or power; or from the union of a few grains of zinc and oxygen, accompanied by the simultaneous disunion of equivalent proportions of oxygen and hydrogen! A force which at the same moment, and in one circuit, will radiate the only light which is capable of rivalling the intensity of the solar beam,—disengage a heat which will fuse the most refractory metal,—control and paralyze the muscular energies of the most powerful animals,—suspend the force of gravity, and give mechanical motion to masses of matter,—and acting upon the ultimate molecules of matter, will decompose the most intimate combinations of affinity at one point, and recompose them at another!!

Mere differences of temperature in some substances, and the mutual friction of others, will also call this marvellous agent forth; and, to complete our admiration, we have now to contemplate it as the product of animal life, and placed as an offensive weapon under the control of animal will.

Animal Electricity.

§ 843. There is a flat fish, a species of ray, which frequents the shores of the Mediterranean, the Atlantic coast of France, and is sometimes taken on the south-west coast of England, which was known to the ancients as capable of communicating a benumbing sensation to those who handled it, and to which they therefore gave the name of *torpedo*. Several of the early physicians, both Roman and Arabian, ascribed to it an influence in subduing obstinate headachs, and the gout itself.

§ 844. The vague notions which were entertained of the nature of this animal force, even in later times, cannot be better exemplified than by an extract from a paper on the subject, published in the *Philosophical Transactions* for 1678, by Stephano Lorenzini. He observes:—" The chief wonder of this animal, and that which gives it its name, is the benumbing faculty which is seated in the two semicircular, or falcated, muscles on each side of the thorax, which consists of fibres, irregular, but as large as a goosequill, and made up of bladders filled with a kind of water; one end of these fibres being fixed to the skin of the belly, and the other to that of the back, on which may be plainly seen the vestigea of the fibres' ends. Now, when the fish contracts those fibres, there issue out corpuscules fitted to the pores of a man's skin, so as to enter upon immediate contact, but not otherwise, and disturb the posture of the parts, and to cause pain, as when one's elbow is hit or knocked; and this comes most by the fingers' ends, because these are ends of tendons. And this pain is more or less as the contraction of the fibres have immitted more or less."

§ 845. As a contrast to these untenable, hypothetical, assumptions, we may refer to a paper on the same property of the torpedo, by Mr. Walsh, in the *Philosophical Transactions* of the year 1773. He set out, also, with an hypothesis, which at the time was sufficiently bold, that the effect was *electrical;* but in the true spirit of the inductive philosophy, he immediately proceeded to test the sufficiency of the supposition by well-devised experiments. He found that the shock of the torpedo could be transmitted through conductors of electricity, as metals and water; and that it was interrupted by non-conductors, as glass and sealing-wax. He discovered that the back and breast of the animal were in different states of electricity; and that to receive the shock, it was necessary that there should be a conducting communication between the upper and lower surfaces. The shock, when in air, appeared to be about four times as strong as when in water. His results have been confirmed and extended by recent experimenters, and particularly by Dr. Davy, who succeeded in effecting chemical decomposition, the magnetization of steel, and the deviation of the magnetic needle, by the electrical current of the torpedo. He also ascertained that the electrical organ upon the under surface of the animal corresponded to the zinc extremity of the voltaic circuit, and its upper surface to the copper extremity (174).

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(174) The figure in the next page presents a view of the under surface of the torpedo. *a* is the right electric organ, exposed by dissecting off the skin, which consists of white pliant columns in a close, and for the most part hexagonal, arrangement, giving a general appearance of a honey-comb in miniature. These columns have been sometimes denominated cylinders; but, having no interstices, they are all angular, and chiefly six-cornered. *b* the skin which covered the organ, showing on its inner side a hexagonal net-work. *c* the nostrils in the form

§ 846. This power of generating and directing an electrical current at pleasure is also possessed by a fresh-water fish, *gymnotus electricus*, which at first view appears very much to resemble an eel, and which consequently has been named the *electrical eel;* a fine specimen of which, forty inches in length, is now being exhibited in the Adelaide Gallery. It is common in all the small rivers which flow into the Orinoco in Guiana, and also in Surinam.

§ 847. Dr. Faraday has lately experimented with this animal, and communicated the results to the Royal Society. He employed two collectors formed of copper-plate bent into a saddle shape, which passed over the fish and enclosed a certain extent of the sides and back, and thick copper wires were brazed to them to convey the electric force to the experimental apparatus. They were covered with sheet caoutchouc, the edges of which projected at the bottom and ends, and the parts of the wires liable to be in the water were also covered with the same substance. By these means, the part of the animal within the caoutchouc was insulated from the surrounding water. The greatest effects were produced when the collectors were applied to the anterior and posterior parts of the gymnotus.

Dr. Faraday concludes, that a single medium discharge of the fish is at least equal to the electricity of a Leyden battery, containing 3500 square inches of glass coated on both sides, charged to its

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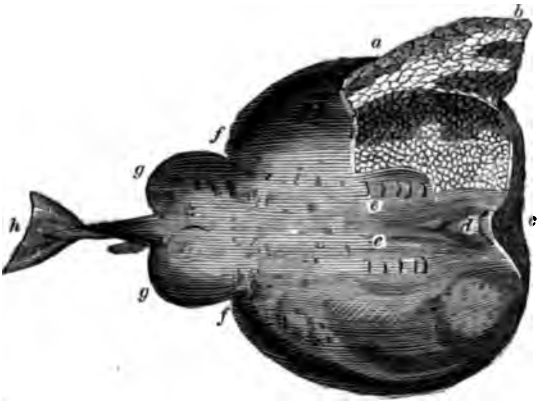
of a crescent. *d* the mouth in a crescent contrary to that of the nostrils, furnished with several rows of very small teeth. *e* the branchial apertures, five on each side. *ff* the outward margin of the greater lateral fin. *g g* the two smaller lateral fins. *h* the fin of the tail.



highest degree; and notwithstanding the greatness of this force, the animal can give a double and triple shock with scarcely a sensible interval of time.

Using the saddle collectors, the needle of a galvanometer, not particularly delicate, was affected to the amount of 40°, and the current was always found to be from the anterior parts of the animal through the galvanometer wire to the posterior parts. An annealed steel needle, placed in a little helix, was rendered magnetic, and polar decomposition of a solution of iodide of potassium was easily obtained. A secondary spark was obtained by means of a good magneto-electric coil, and afterwards a direct spark between the surfaces of two gold leaves (175).

§ 848. It was evident from the experiments, that all the water and all the conducting matter around the fish, through which a discharge circuit can in any way be completed, is filled at the moment with circulating electric power; and a number of persons all dipping their hands at the same time into the tub, the diameter of which was 46 inches, received a shock of greater or less intensity accordingly as they were more or less favourably situated with regard to the direction of the current.

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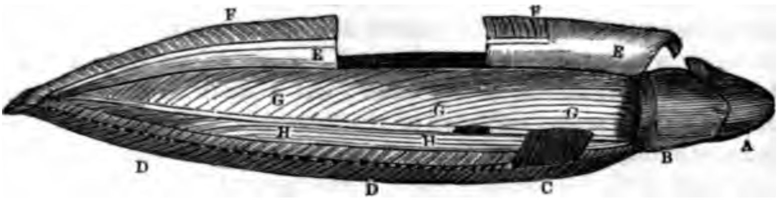
(175) This figure exhibits the whole of the two electrical organs on each side of the gymnotus, the skin being removed as far as these organs extend. They consist of two parts; viz., flat partitions or septa, and cross divisions between them. The outer edge of these septa appear externally in parallel lines, nearly in the direction of the longitudinal axis of the body. These septa are thin membranes, placed nearly parallel to one another. Their breadth is nearly the semi-diameter of the body of the animal. They are of different lengths, some being as long as the whole organ. A the lower surface of the head of the animal: B the cavity of the belly: C the back of the fish where the skin has not been removed: D D the fin which runs along the lower edge of the fish: E E the skin turned back: F F the lateral muscles of the above fin removed, and carried back with the skin, to expose the small electrical organ: G G G the large electrical organ: H H the small organ.



§ 849. The gymnotus can stun and kill fish which are in various positions with respect to its own body. On one day, when Dr. Faraday particularly observed it, a live fish was dropped into the tub, and the gymnotus instantly turned round in such a manner as to form a coil enclosing the fish, the latter representing a diameter across it. A shock passed, and, in an instant, the fish was struck motionless, as if by lightning, in the midst of the waters, its side floating to the light. The gymnotus made a turn or two to look for its prey, which, having found, he swallowed, and then went searching about for more.

§ 850. To obtain an adequate idea of the power with which this extraordinary fish is armed, we must have recourse to the accounts of its action in its native streams; and the Baron De Humboldt has furnished us with the following graphic description of the Indian mode of fishing for gymnoti, by means of horses:—

"The exraordinary noise caused by the horses' hoofs, makes the fish issue from the mud, and excites them to combat. These yellowish and livid eels, resembling large aquatic serpents, swim on the surface of the water, and crowd under the bellies of the horses and mules. A contest between animals of so different an organization furnishes a very striking spectacle. The Indians, provided with harpoons and long slender reeds, surround the pool closely; and some climb upon the trees, the branches of which extend horizontally over the surface of the water. By their wild cries, and the length of their reeds, they prevent the horses from running away, and reaching the bank of the pool. The eels, stunned by the noise, defend themselves by the repeated discharge of their electric batteries. During a long time they seem to prove victorious. Several horses sink beneath the violence of the invisible strokes, which they receive from all sides in organs the most essential to life; and stunned by the force and frequency of the shocks, disappear under the water. Others, panting, with mane erect, and haggard eyes, expressing anguish, raise themselves, and endeavour to flee from the storm by which they are overtaken. They are driven back by the Indians into the middle of the water; but a small number succeed in eluding the active vigilance of the fishermen. These regain the shore, stumbling at every step, and stretch themselves on the sand, exhausted with fatigue, and their limbs benumbed by the electric shocks of the gymnoti. By degrees the impetuosity of this unequal combat diminished, and the wearied gymnoti dispersed. They require a long rest, and abundant nourishment, to repair what they have lost of galvanic force. The mules and horses appear less frightened; their manes are no longer bristled, and their eyes express less dread. The gymnoti approach timidly the edge of the marsh, where they are taken by means of small harpoons fastened to long cords. When the cords are very dry, the Indians feel no shock in raising the fish into the air*."

§ 851. In the anatomical construction of these animals, as displayed in the dissections of Mr. John Hunter, the most striking thing is the large proportion which the electrical organs bear to the rest of the bodies of the animals. In both species we recognise a structure which is contrived for large extension of surface in a small space, which reminds us of the similar construction of our voltaic arrangements. These are so abundantly supplied with nerves, as to have lead Mr. Hunter to remark with regard to torpedos, that "the magnitude and the number of the nerves bestowed on their organs, in proportion to their size, must, on reflexion, appear as extraordinary as the phenomena which they afford," and in speaking of the gymnotus, he says, "in this fish, as well as in the torpedo, the nerves which supply the organ are much larger than those which are bestowed on any other part for the purposes of sensation and action."

The electric organs of the torpedo and gymnotus cannot be considered as connected with those which are of direct importance to the life of the animal, but to belong rather to the common teguments; and it has been found that such torpedos as have been deprived of the use of their peculiar organs, have continued the functions of life quite as well as those in which they were allowed to remain.

The nervous energy of the animals evidently becomes exhausted during the production of electricity, and there is an apparent production of electricity, equivalent to the quantity of nervous force consumed.

§ 852. Living as these animals do in the midst of so good a conductor as water, our first thoughts are thoughts of surprise, that they can sensibly electrify anything, but a little consideration makes the perfect design of the whole arrangement obvious. It is by the conducting power of the water alone that the force can be communicated to the animal to be struck, and we may contrast this state of things with what would result, if the body of the fish or its victim were surrounded with air.

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* *Personal Narrative.* Chap. xvii.

The fate of a gymnotus which had been caught and confined for the purpose of transmission to this country will illustrate the point. This animal, notwithstanding its wonderful powers, was doomed to perish ignobly under the attacks of a water-rat. Much surprise was excited by this catastrophe; but all wonder ceases when we consider the perfect manner in which the body of the rat is insulated. When he dives beneath the water, not a particle of the liquid adheres to him, and his non-conducting fur, and the air which it contains, clothes him with armour which is perfectly proof against the bolts of his formidable antagonist.

§ 853. Never was there a more tempting field of research, or a higher reward offered for its successful cultivation, than that which is presented by *animal electricity*. In these electric fish we behold nervous power converted into electric force; it cannot be doubted that the converse of this is possible. We are, however, only upon the threshhold of this inquiry of surpassing interest. It belongs, indeed, exclusively to the physiologist to connect these two branches of physical philosophy; but he who would take up the investigation with any hopes of success, must not only be well skilled in comparative anatomy and dissections, and conversant with the vital functions of animals, but must be master of all that is known of that extraordinary agent, the laws of which we have been endeavouring to expound under the names of *current affinity and electricity*, and must follow with zeal and industry, the rapid progress which science is daily making in their development.

§ 854. The phenomena of the electric fish have lost none of their interest since the days when Mr. Walsh first communicated his experiments upon the torpedo to Dr. Franklin, and we cannot better take leave of the subject, at present, than by recalling the words with which he closed his letter upon the subject to that eminent philosopher.

"I rejoice in addressing these communications to you. He, who predicted and showed that electricity wings the formidable bolt of the atmosphere, will hear with attention, that in the deep it speeds a humbler bolt, silent, and invisible. He, who analyzed the electrified phial, will hear with pleasure that its laws prevail in animate phials. He, who by reason became an electrician, will hear with reverence of an instinctive electrician, gifted in his birth with a wonderful apparatus, and with skill to use it*."

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* *Philosophical Transactions*, 1773.

ATOMIC THEORY.

§ 855. In the preparatory view of the forces with which matter has been endowed, which we have been presenting to the student of natural science, we set before him, in the first place, the conception which the mind of Newton had formed of the atomic constitution of matter (§ 7). The same hypothesis may be traced back to the writings of Epicurus and his followers, and even to earlier times; and in this, as well as many other instances, we cannot but admire the acuteness of intellect which at so early a period of philosophy, propounded speculations upon the constitution of the universe, which have stood their ground till the present advanced state of science. The intellectual vigour of the philosophers of antiquity, indeed, was capable of the grandest and most comprehensive views of nature, and often conducted them to the most sublime truths, but in attempting perpetually to soar above the vulgar paths of observation and experience, they speedily became confounded in the mists of error and conceit.

The atomic doctrine, although at first sight it might appear to belong exclusively to *metaphysical science*, has received its greatest support from the progress of chemistry in modern times, and Dr. Dalton, the great discoverer of the theory of multiple and equivalent proportions, clothed his views from the first in the language of this speculation: and, hence, the term *atom* is now often used by writers and lecturers as synonymous with *equivalent*.

The law of multiple proportions is, in fact, a necessary consequence of the atomic hypothesis; for if bodies combine only atom with atom, or one atom with two, &c.—the weight of such atoms having a fixed relation of weight to one another—it is clear that whatever may be the aggregate number of particles so combining the total weight of one sort, must be in the same proportion to the total weight of the other sort.

All the phenomena are, in fact, irreconcilable with the rival hypothesis of the infinite divisibility of matter.

§ 856. With regard to the *absolute* weights, sizes, and numbers of the ultimate particles of matter, nothing of course can be determined; nothing, moreover, with regard to the *absolute* quantities of heat, electricity or attraction with which they may be associated or endued; but speculations upon the *relative* proportions which the atoms of different species of matter bear to one another, in these respects, have been supported by experimental evidence and inductive reasoning of the most ingenious description. These, perhaps, are best kept out of sight in the first steps of physical investigations, as likely to turn the mind from that rigid method of induction from facts, by which alone the student can be safely guided; but in a more advanced stage they have their use in expanding the mind, and in imparting a lively interest to the subject. We shall, therefore, conclude this view by illustrating the mode of reasoning, by which, on one hand, the atomic theory has been supported by experiment, and by which, on the other, it has been made the means of suggesting experimental inquiry.

§ 857. Dr. Dalton announced the important, but simple generalization at which he had arrived in the following terms*:—

"In all chemical investigations, it has justly been considered an important object to ascertain the relative *weights* of the simples which constitute a compound. But, unfortunately, the inquiry has terminated here; whereas, from the relative weights in the mass, the relative weights of the ultimate particles or atoms of the bodies might have been inferred, from which their number and weight in various other compounds would appear, in order to assist and to guide future investigations, and to correct their results. Now, it is one great object of this work to show the importance and advantage of ascertaining, *the relative weights of the ultimate particles, both of simple and compound bodies, the number of simple elementary particles which constitute one compound particle, and the number of less compound particles which enter into the formation of one more compound particle.*

"If there are two bodies, A and B, which are disposed to combine, the following is the order in which the combination may take place, beginning with the most simple: namely,—

1 atom of A + 1 atom of B = 1 atom of C binary.
1 atom of A + 2 atoms of B = 1 atom of D ternary.
2 atoms of A + 1 atom of B = 1 atom of E ternary.
1 atom of A + 3 atoms of B = 1 atom of F quaternary.
3 atoms of A + 1 atom of B = 1 atom of G quaternary."
&c., &c.

He proceeds to lay down the following general, but arbitrary, rule, as a guide to all our investigations respecting this species of hypothetical synthesis: and this rule, in fact, constitutes the fixed point from which calculation must set out; the fulcrum from which the hypothesis must be applied:—

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* *New System of Chemical Philosophy*, vol. i. p. 212.

"1st. When only one combination of two bodies can be obtained, it must be presumed to be a *binary* one, unless some cause appear to the contrary.

"2nd. When two combinations are observed, they must be presumed to be a binary and a ternary," &c.

§ 858. In this statement, it will be perceived, that Dr. Dalton has associated the fact, that the proportion in which bodies combine follows the numerical laws upon which we have already laid so much stress, with the hypothesis, that the union in all cases takes place between the atoms which constitute the substance in question; and that, in each substance, the atoms are themselves characterized by a proportionate difference in point of weight (176).

§ 859. With regard to the shape of the atomic particles, we have already given the rival hypotheses of polyhedral and spheroidal forms in discussing the subject of crystallization, and stated the reasons for concluding that the latter is the more probable of the two.

The spheroidal hypothesis has received a further extension by supposing that the structure of bodies is not simply due to their mutual powers of attraction, but to a balance between the attractive force of the atoms and the repulsive power of an elastic atmosphere,

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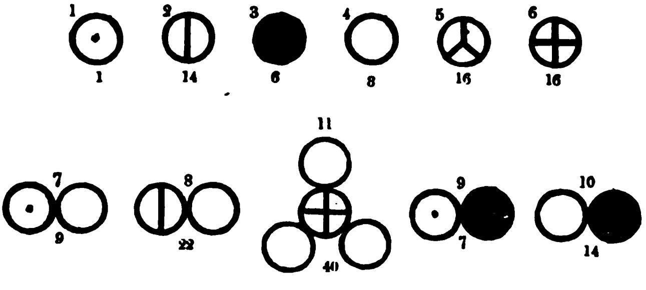
(176) These are some of the arbitrary marks, or signs, chosen by Dr. Dalton, to represent the several chemical elements and their compounds. The relative weights of the atoms are placed under them :—



1 represents the atom of hydrogen; 2 nitrogen; 3 carbon; 4 oxygen; 5 phosphorus; 6 sulphur; 7 represents the compound atom of water; 8 protoxide of nitrogen; 9 carburetted hydrogen; 10 oxide of carbon; 11 sulphuric acid.

with which we may conceive each to be surrounded, and which is sometimes assumed to be the matter of heat. The atoms are imagined to be attractive of each other and of the particles of the hypothetical atmosphere, but the latter highly repulsive of each other.

§ 860. Upon these postulates each *spherical* atom would be surrounded by a stratum of equal depth in all its parts, uniformly distributed over its surface, which, preventing the actual contact of the particles, would nevertheless allow them to arrange themselves according to the laws of the predominant attraction.

Any addition or diminution of the repulsive *aura* would cause the atoms to recede from or approach towards each other equally; and if we were to heat a solid so constructed it would expand equally in all directions.

But this would not be the case with oblate spheroids instead of spheres. For, in the first place, as the force of their attraction upon the particles of the *aura*, must, from the nature of their form, be exerted with greater force in the direction of their shorter axes than in that of their longer, the centre of the spheroid being nearer to them in this direction;—taking for granted two fundamental laws of attraction, first, that all the particles of matter attract one another directly as their masses, and inversely as the squares of their distances; secondly, that a body of any shape will attract a particle of matter anywhere, with the same force and in the same direction, as if all the matter of that body were collected in its centre of attraction,—it is clear that their repulsive atmospheres would not be distributed in equal layers over their surfaces, but would be collected in greater depth above the shorter axes than the longer; and the atoms, with their atmospheres, would assume more of the spherical form than belongs to the atom alone (177).

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(177) We may suppose Fig. 1 to represent a section of the tetrahedral arrangement of spheres in simple contact; and Fig. 2 of the same spheres, with their atmospheres: an arrangement essentially the same with regard to structure and external figure. Any addition or diminution of the repulsive *aura* would cause the atoms to approach towards and recede from each other equally.

Fig. 1.

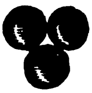


Fig. 2.

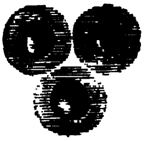


Fig. 3.

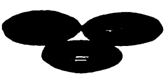
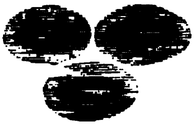


Fig. 4.

Fig. 5.



§ 861. A solid crystal, therefore, thus constructed, must change the measure of its angles with every change of temperature. As we have already seen (§ 122), this is precisely what Professor Mitscherlich has ascertained to happen with crystals of carbonate of lime and other substances not crystallizing in the regular octohedral series. In substances crystallizing in this series he also ascertained that the expansion was equal in all directions.

These consequences might have been anticipated from the hypothesis, and the observation of the actual phenomena tends powerfully to its support.

§ 862. Passing from the consideration of the weights and forms of the atoms of different kinds of matter to their relative distances, it has been argued that the particles of all elastic fluids are placed at equal distances from each other, and that equal measures of such fluids contain an equal number of particles. This opinion is founded upon their equal dilatation and contraction by equal changes both of pressure and temperature. The fact of the same force, applied to different gases, attracting or repelling their atoms to the same amount leads to the conclusion that under similar circumstances their distances must be the same.

It follows also from this assumption that the atomic weights of simple gases must be proportionate to their densities, and that these may be determined by experiment, not only with bodies which are naturally in a gaseous state, but with such bodies as are volatile below the fusing point of glass, by which our experiments are limited.

§ 863. The following table exhibits the specific gravities of the several gases and vapours named in the first column, the atomic weights derived from this calculation, and the equivalent proportions in which they combine, or what we must now regard as the atomic weights derived from their affinities:—

Fig. 3 represents a section of the tetrahedral arrangement of oblate spheroids in simple contact; and Fig. 4 an oblate spheroid with its atmosphere, which is collected, according to the laws of attraction, in a layer of greater depth above the shorter axis than above the longer. In Fig. 5 we are presented with the tetrahedral arrangement of similar spheroids; from which it is clear that any addition to their atmospheres, according to the same laws, will cause a greater expansion in the direction of the shorter axis than in that of the longer.

TABLE XXXVII. *Atomic and Equivalent Weights.*

	Specific gravity from Experiment	Atomic Weight.	Equivalents.
Hydrogen . . .	0.0688	1.0 =	1.0
Oxygen	1.1026	16.0 =	8.0 × 2
Nitrogen	0.9760	14.1 =	14.0
Chlorine	2.4700	35.9 =	36.0
Bromine	5.5400	80.5 =	78.0
Iodine	8.7160	126.6 =	125.0
Phosphorus . . .	4.4200	64.2 =	16.0 × 4
Arsenic	10.6000	154.0 =	38.0 × 4
Sulphur	6.6170	96.1 =	16.0 × 6
Mercury	6.9760	101.3 =	200.0 ÷ ½

Here we at once see that the atomic weights thus derived from specific gravity, allowing for very minute errors of experiment, are either identical with, or simple multiples and sub-multiples of, the equivalents derived from chemical combination. That they are not in every case identical requires a modification of the hypothesis, and to reconcile the two, we must admit that the number of atoms in the same volume of the different gases is not equal, but that they bear some simple proportion to one another, as 1 : 1, or 1 : 2, or 1 : 3, &c., or that the compounds which were supposed to be binary, or atom with atom, are in some cases binary, quaternary, &c.

§ 864. With regard to liquids in general, the inequality of their expansion by heat would seem to lead to a directly opposite conclusion to that which we have arrived at with regard to aëriform bodies; nevertheless their particles may offer simple points of relation to each other, if the comparison be made under exactly similar circumstances. M. Gay Lussac has proved this by showing that equal volumes of alcohol and sulphuret of carbon, measured at equal distances from their respective boiling-points, and allowed to cool an equal number of degrees, will always remain equal.

This result is exhibited in the following Table, in which will be found the contractions which 1000 parts of these two liquids undergo for every 9° of Fahrenheit, setting out from the boiling-point of each :—

TABLE XXXVIII. *The Contractions of Alcohol and Sulphuret of Carbon.*

Number of Degrees by which the Temperature was lowered.	Contraction of 1000 parts of Alcohol, from the Temperature 173.5°.	Contraction of 1000 parts of Sulphuret of Carbon from 113°.
9	5.55	6.14
18	11.43	12.01
27	17.51	17.98
36	24.34	23.80
45	29.15	29.65
54	34.74	35.06
63	40.28	40.48
72	46.68	45.88
81	50.85	51.08
90	56.02	56.28
99	61.01	61.14
108	65.96	66.21

As these contractions are sensibly equal, it is clear that the volumes of the two liquids must be equal at the temperatures denoted: and to compare them under equal circumstances, it is necessary to maintain between them the thermometric interval which separates their points of ebullition.

Equal volumes of alcohol and sulphuret of carbon measured with this precaution would give equal volumes of vapour measured at the same temperature and pressure; and this theoretical conclusion has been confirmed by experiment.

§ 865. Hence we might conclude that if equal volumes of the two vapours contain an equal number of atoms, equal volumes of the liquids, measured under the conditions which we have just pointed out, must do the same.

This is, however, by no means a general law; but still there is reason to suppose that an intimate relation would be found between liquids and their vapours, provided a comparison were instituted either at their boiling points, or at their points of greatest viscosity.

§ 866. The atomic weights of bodies are not only thus dependent upon their specific gravities, but are intimately connected with their specific heats. We have seen that when we compare the same weight of two substances together, their capacities for heat are very unequal (Table XIII.); but if we make the same comparison between quantities proportional to their equivalent numbers, we shall find their capacities almost always equal. This remarkable law was discovered by MM. Du Long and Petit. It may otherwise be expressed thus:—The specific caloric of simple bodies is inversely as their atomic weights; and a given quantity of heat will elevate the same number of degrees a portion of every simple substance represented by its atomic weight. Thus, it requires twice as much heat to elevate the temperature of a pound of sulphur, whose equivalent number is 16, 10°, as it does to raise that of a pound of zinc, whose equivalent is 32, to the same extent; and a pound of heated sulphur will warm twice as much water, or any third substance, as a pound of equally hot zinc.

Now as, according to our hypothesis, the number of particles which equal weights of any two substances comprise, is in inverse proportion to the weights of these particles, the law in question may be verified by multiplying the capacities, determined by experiment, by the weights of the corresponding atoms. If the law be true, the products of the multiplication should be sensibly equal, or differ from one another by quantities so small as to fall within the limits of errors of experiment.

§ 867. The following Table exhibits the specific heats of thirteen simple substances, the atomic weights which correspond with them, the product of the multiplication of these two numbers, and the atomic weights derived from their chemical combinations:—

TABLE XXXIX. *Correspondence of Atomic Weights and Specific Heats.*

	Specific Heat.	Atomic Weights.	Product of the Two.	Chemical Atomic Weights.
Bismuth . . .	0.0288	108	31.10	72
Lead	0.0293	104	30.47	14
Gold	0.0298	100	29.80	200
Platinum . . .	0.0314	96	30.14	96
Tin	0.0514	58	29.81	58
Silver	0.0557	55	30.63	110
Zinc	0.0927	32	29.66	32
Tellurium . . .	0.0912	32	29.18	32
Copper . . .	0.0949	32	30.36	32
Nickel	0.1035	28	30.38	28
Iron	0.1100	28	30.80	28
Cobalt . . .	0.1498	20	29.96	30
Sulphur . . .	0.1880	16	30.08	16
		Mean . .	30.18	

§ 868. Admitting, therefore, the truth of the law, if we know the capacity of any simple body for heat, we have only to divide by it the number 30.18, the mean product of the Table, to obtain the relative weight of its atom compared to hydrogen. But here, again, it will be observed that the atomic numbers derived from the specific heats are not in all cases identical with those derived from chemical combination; but still they are connected together by the simple relations of multiple and sub-multiple.

§ 869. It has also been found by M. Neumann, that the atoms of compound bodies of analogous composition, are endued with the same capacity for heat, as the following results of the two classes of carbonates and sulphates will show.

TABLE XL. *Correspondence of Atomic Weights and Specific Heats in the Carbonates.*

	Specific Heat.	Atomic Weights.	Product of the two.
Carbonate of Lime . . .	0.2044	50	102.2
Carbonate of Baryta . .	0.1080	99	106.9
Carbonate of Iron . . .	0.1819	58	105.5
Carbonate of Lead . . .	0.0810	134	108.5
Carbonate of Zinc . . .	0.1712	62	106.1
Carbonate of Strontia . .	0.1445	74	106.9
		Mean . .	106.

TABLE XLI. *Correspondence of Atomic Weights and Specific Heats in the Sulphates.*

Sulphate of Baryta . .	0.1068	117	124.9
Sulphate of Lime . . .	0.1854	68	126.0
Sulphate of Strontia . .	0.1300	92	119.6
Sulphate of Lead . . .	0.0830	152	126.1
		Mean . .	124.1

In these instances, the atomic weights exactly correspond with those derived from the chemical composition of the several salts.

§ 870. The like intimate connexion exists between the atoms of bodies and electricity: the *specific electricity* of different substances, is inversely as their atomic weights, and a given quantity of electricity will separate from combination portions of substances represented by their atomic weights. Thus, the action of 32 parts of zinc, in a voltaic battery, is able to evolve a current of electricity which is capable of decomposing and transferring the elements of 9 parts of water, and of disengaging 1 part of hydrogen and 8 parts of oxygen. Or: if we have recourse to another source for the electricity; the same current derived from the induction of a magnet, which will decompose 9 parts of water into 1 hydrogen, and 8 of oxygen will, at the same time, decompose 37 parts of muriatic acid into 1 of hydrogen, and 36 of chlorine.

This is another mode of representing the grand discovery of Faraday, and it will be seen from the following Table, that the atomic weights experimentally obtained by him by electrical decomposition, accord with those derived from chemical composition. The calculated specific electricity of equal weights of the different substances, is placed by the side of their atomic numbers.

TABLE XLII. *Electro-Chemical Equivalents.*

CATIONS.			ANIONS.		
	Equivalents.	Specific Electricity.		Equivalents.	Specific Electricity.
Hydrogen	1.	1000	Oxygen	8.	125
Potassium	39.2	25	Chlorine	35.5	27
Sodium	23.3	43	Iodine	126.	8
Zinc	32.5	31	Bromine	78.3	12
Copper	31.6	31	Fluorine	18.7	55
Ammonia	17.	58	Cyanogen	26.	38
Potassa	47.2	21	Sulphuric acid	40.	25
Soda	31.3	32	Nitric acid	54.	18
Lime	28.5	35	Chloric acid	75.5	13

§ 871. This mode of viewing the atomic constitution of bodies in relation to space, gravity, affinity, heat, and electricity, not only presents us with the most interesting, although imperfect, glimpses of the order of the material creation, but may be practically useful by enabling us to correct the data which we derive from one order of relations by those deduced from another. Thus, with regard to the chemical equivalents, or combining proportions of some substances, chemists have been sometimes in doubt between two numbers, one the multiple of the other; which doubt might be resolved by an appeal to their specific heats, or electrolytic products. For a long time, opinions were divided between the numbers 64 and 32, for copper, either of which can be defended upon purely chemical grounds, with arguments of equal plausibility: both the relations, however, of heat and electricity agree in the latter number.

§ 872. There are some instances, however, in which the weights of the atoms derived from physical considerations, as contradistinguished to chemical, are at present irreconcileable with the latter, although still connected with them by simple relations. The bold spirit of hypothesis, far from being checked by the difficulty, hereupon suggests that chemical atoms, those infinitely small particles which are indivisible by chemical forces, may be divisible by heat, and that, for example, the chemical atoms of mercury are divided into two when they pass into the gaseous state.

§ 873. The forms of the ultimate atoms of different kinds of matter have also been appealed to for confirmation of their respective weights. It was long ago remarked by M. Gay Lussac, that, in the composition of alum, ammonia might be substituted for potassa without at all interfering with the shape of its crystals; and that a crystal of ammoniacal alum, when placed in a saturated solution of potassa alum, would go on increasing in size without undergoing any modification of form. M. Mitscherlich has since discovered that salts, or in general any chemical compounds, which can be represented by the same atomic formula, may crystallize together, and become mixed in any proportions in the crystals, without modifying the fundamental form beyond a few degrees in the measure of their angles. He supposes that the molecules of all such substances have the same forms, and that therefore one is capable of taking the place of another without leaving any vacuity. This identity of shape and faculty of substitution belongs to bodies of all classes. Simple substances, oxides, sulphurets, salts, and organic matters, may possess them, and it may therefore be considered as a general property of bodies. Professor Mitscherlich has designated it by the name of ISOMORPHISM: he denominates *isomorphous*, substances that crystallizing in the same shape can substitute themselves one for the other without changing the form of the product, and he regards them as being generally composed of the same number of atoms united in the same manner.

§ 874. This last condition, which agrees in a great number of cases with chemical data, being conceded, we have it in our power to determine the atomic weights of simple substances which have not yet had their specific heat, or their density in a state of vapour, determined.

For an example of this mode of reasoning, let us take iron, whose atomic weight determined by its specific heat agrees with the chemical equivalent 28; from the analysis of its two principal oxides we are led to the following conclusions.

The protoxide of iron contains:—

$$\left.\begin{array}{ll}\text{Iron} & 77.23\\ \text{Oxygen} & 22.77\end{array}\right\}100.00$$

	Iron.		Oxygen.		1 Equiv. Iron.		1 Equiv. Oxy.
And,—	77.23	:	22.77	::	28	:	8

The protoxide, therefore, contains one atom of each element.

The sesqui-oxide of iron contains:—

$$\left.\begin{array}{ll}\text{Iron} & 69.34\\ \text{Oxygen} & 30.66\end{array}\right\}100.00$$

	Iron.		Oxygen.		1 Equiv. Iron.		1½ Equiv. Oxy.
And,—	69.34	:	30.66	::	28	:	12

The sesqui-oxide, therefore, contains 1 atom of iron and 1½ oxygen, or 2 atoms of iron and 3 of oxygen.

Now, the oxide of iron may be replaced in the carbonate or sulphate of iron by a great number of oxides; as magnesia, lime, protoxide of manganese, oxide of zinc, &c. The analysis of the oxides, therefore, being known, nothing can be easier than to determine the atomic weight of the metal when unknown.

§ 875. It is known, for instance, that lime contains:—

$$\left.\begin{array}{ll}\text{Calcium} & 71.4\\ \text{Oxygen} & 28.6\end{array}\right\}100.0$$

Knowing, from the law of isomorphism, that lime must contain one atom of calcium and one atom of oxygen, we state the following proportions:—

Oxygen.		Calcium.		1 Oxygen.		Atomic Number.
28.6	:	71.4	::	8	:	20

And in the same manner we may proceed with the numerous other metals whose oxides are isomorphous with the preceding.

§ 876. On the other hand, knowing the number of atoms of metal and oxygen which the sesqui-oxide of iron contains, we may easily find the atomic weights of such metals as afford oxides isomorphous with it. It is known, for example, that the sesqui-oxide of iron, the sesqui-oxide of manganese, and the oxides of chrome and aluminum, can replace one another, and become intimately blended in the composition of alum, without changing the form of the salt. Hence we conclude, that each of these oxides contains two atoms of metal for three atoms of oxygen.

Thus we know that alumina is composed of:—

Aluminum	53.29	100.00
Oxygen	46.71	

And from these data we obtain the atomic weight of aluminum, thus:—

Oxygen.		Alumina.		3 Oxygen.		Atomic Number.
46.71	:	53.29	: :	24	:	27

§ 877. We will take a last illustration of the principle under consideration from manganese, which will prove at once how various and how unerring are the indications of isomorphism.

The protoxide of manganese is isomorphous with the protoxide of iron, and therefore contains one atom of metal to one atom of oxygen. From its composition per cent. we derive the following result:—

Oxygen.		Manganese.		1 Oxygen.		Atomic Number.
21.94	:	78.06	: :	8	:	28

The sesqui-oxide of manganese is isomorphous with the sesqui-oxide of iron, and from its known composition:—

Oxygen.		Manganese.		1½ Oxygen.		Atomic Number.
29.66	:	70.34	: :	12	:	28

The manganic acid, again, is isomorphous with the sulphuric acid; and from the atomic number of sulphur derived from its specific heat, the latter contains one atom of sulphur to three atoms of oxygen. We must therefore adopt the same formula for the former, and its analysis will lead to the following proportion:—

Oxygen.		Manganese.		3 Oxygen.		Atomic Number.
46.45	:	53.55	: :	24	:	28

And lastly, the hyper-manganic acid is isomorphous with the hyper-chloric acid; and as this is composed of two volumes of chlorine to seven of oxygen, we must conclude that the hyper-manganic acid itself is composed of one atom of manganese to three and a half of oxygen, so that we derive the following proportion from its analysis:—

Oxygen.		Manganese.		3½ Oxygen.		Atomic Number.
50.29	:	49.71	: :	28	:	28

Thus four distinct classes of combinations all lead to the same result, and we cannot doubt that with regard to simple substances, which cannot even be examined by other methods, isomorphism is capable of leading us to correct results.

§ 878. We have now to remark an evident relation between the atomic weights of certain substances and their densities in the solid state; thus amongst the metals, those which have the highest numbers have also the highest specific gravities. Hence when the atomic weight has been fixed by no other consideration, we are disposed to conclude that a heavy metal has a high equivalent, and a light metal a low one. The metals which have a specific gravity higher than 9, have all atomic weights above 96, and those below that density seldom exceed 32 or 40. But knowing the weights of equal volumes of two simple substances, and the weights of their particles, the relation between the distances of the particles of these two bodies, or of the spaces which they occupy, may be calculated. Or, which is the same thing, we may compare the number of the atoms in equal volumes of the substances. The density divided by the atomic weight of one will be to the density divided by the atomic weight of the other, as the number of atoms in a volume of the first to the number of atoms in an equal volume of the second. These relations are found to be of extreme simplicity when we compare together substances which can be classed together by marked analogies. Let us compare, for example, the following five isomorphous metals:—

	Densities.	Atomic Weights.	Number of Atoms in Equal Volumes.
Iron	7.8	28	0.277
Cobalt . . .	8.5	30	0.280
Nickel	8.6	28	0.300
Copper . . .	8.9	32	0.278
Manganese . .	8.0	28	0.280
		Mean . .	0.283

The numbers in the last column differ too little from the mean to allow us to doubt that to their other analogies we may add that of containing the same number of atoms in the same volumes.

If we add carbon to this list, we shall have the following result:—

	Density.	Atomic Weight.	Number of Atoms.
Diamond	3.4	6	0.56

From which we conclude that the number of atoms in an equal volume of carbon bears the simple relation to the former of a duplicate ratio. There may at first appear to be little analogy between the preceding metals and carbon; but it is worthy of remark, that melted iron is capable of dissolving carbon in large quantities, and of throwing it off in a lamellar state in the act of cooling; as if the particles of iron and carbon were capable of mutual interposition, and occupied spaces simply proportioned to each other.

§ 879. The metals molybdenum and tungsten offer a most striking example of this accordance, for while they are united by the strongest analogy of properties, they are separated by the greatest differences of densities and equivalents:—

	Densities.	Atomic Weight.	Number of Atoms.
Molybdenum . . .	8.6	48	0.17
Tungsten	17.4	100	0.17

§ 880. One more example we will select from a comparison between the lightest and heaviest elementary solids with which we are acquainted:—

	Densities.	Atomic Weight.	Number of Atoms.
Sodium	0.972	24	0.040
Potassium . . .	0.865	40	0.020
Platinum	21.500	96	0.200

Here we see that, in an equal volume, platinum contains just five times as many atoms as sodium, and ten times as many as potassium.

§ 881. The phenomena to which we have before referred of *dimorphism* (§ 126) and *isomerism* (§ 511) are also intimately connected with the atomic theory. To the former belong those changes in a body which, without altering its composition or its chemical character, modify its physical properties, such as its density, its hardness, its cohesion, its colour, or its crystalline form. They are conceived to depend upon some alteration in the arrangement of the molecular groups of the bodies in which they occur. Under the latter are classed together all those bodies which present the same composition, but which differ essentially in their chemical properties; and their differences are doubtlessly connected with differences in the arrangement of the elementary atoms or proper chemical atoms of which they are composed.

§ 882. The atomic theory thus connects together, by an hypothesis of extreme simplicity, a vast multitude of phenomena which could scarcely be comprehended together in any other general view; and it is scarcely possible to overrate its importance. In it we recognise one of "those higher inductions, in which more scope is given to the exercise of pure reason than in slowly groping out our first results; and the mind is more disencumbered of matter, and moves, as it were, in its own element."

But we must be careful not to abuse this liberty of speculation, which is one of the highest privileges of the well-trained intellect, and the student of the atomic doctrines will do well to imprint upon his mind the caution of that eminent philosopher, to whom we have already been so greatly indebted for our rules of philosophizing, that "We are not, therefore, to suppose that we are abandoned to the unrestrained exercise of the imagination, or at liberty to lay down arbitrary principles, or assume the existence of mere fanciful causes." "The ultimate objects we pursue in the highest theories are the same as those of the lowest inductions; and the means by which we can most securely attain them bear a close analogy to those which have been found successful in such inferior cases*."

§ 883. We have thus filled up our plan; and we hope that the view which has resulted of the *connexion of the physical sciences*, may be useful to students in preparing them for that closer and more laborious examination of the principles of chemical philosophy, which will be necessary for the attainment of proficiency in that or any other department of science. "It can hardly be pressed forcibly enough on the attention of the student of nature," observes Sir John Herschel, "that there is scarcely any natural phenomenon which can be fully and completely explained in all its circumstances without a union of several, perhaps of all, the sciences;" and it cannot be doubted that, whatever walk of science he may determine to pursue, impossible as it is for a finite capacity to explore all with any chance of success, he will find it illuminated in proportion to the light which he is enabled to throw upon it from surrounding regions. But independently of this advantage, the glimpse which may thus be obtained of the harmony of Creation,—of the unity of its plan—of the theory of the material universe, is one of the most exalted objects of contemplation which can be presented to the faculties of a rational being. In such a general survey he perceives that science is a whole, whose source is lost in infinity, and which nothing but the imperfection of our nature obliges us to divide. He feels his nothingness in his attempts to grasp it, and he bows with humility and adoration before that SUPREME INTELLIGENCE who alone can comprehend it; and who "in the beginning *saw every thing* that he had made, and behold it was very good."

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* HERSCHEL'S *Discourse*, pp. 190, 191.

GLOSSARY.

Absorption, from *absorbeo*, to suck up; the power or act of imbibing a fluid.

Acetic Acid, from *acetum*, vinegar; the acidifying principle of common vinegar.

Acicular, from *acus*, a needle; having sharp points like needles.

Acoustics, from ἀκούω, to hear; the science which relates to sounds.

Action, from ἄγω, to move; the effort by which one body produces, or endeavours to produce, motion in another.

Adhesion, **-ive**, from *ad*, to, and *hæreo*, to stick; the tendency which dissimilar bodies have to adhere or stick together.

Aëration, from ἀὴρ, the air; the saturation of a liquid with air.

Aëriform, from *aer*, the air, and *forma*, a form; having the form of air.

Aërostation, from ἀὴρ, the air, and ἵστημι, to weigh; primarily it denotes the science of weights suspended in the air, but in the modern application of the term, it signifies the art of navigating the air.

Affinity, from *ad*, to, and *finis*, a boundary; relationship; the force which causes dissimilar particles of matter to combine together so as to form new matter.

Albumen, **-inous**, from *albumen*, the white of an egg; an important animal principle. The white of an egg is albumen mixed with water.

Alcohol, from a word of Arabic origin; the intoxicating ingredient of spirituous liquors.

Alkali, a soluble body, with a hot caustic taste, which possesses the power of destroying acidity; the term is derived from *kali*, the Arabic name of a plant, from the ashes of which one species is obtained, and the article *al*.

Alumina, the base of alum; pure clay.

Amalgam, from ἅμα, together, and γαμέω to marry; a chemical term, signifying the union of any metal with mercury, which is a solvent of various metals.

Amorphous, from ἀ, not, and μορφὴ, a form; not possessing regular form.

Analogy, **-ical**, and **-ous**, from ἀνὰ, thoroughly, and λόγος, a relation or proportion; a likeness or resemblance between things with regard to their circumstances or effects.

Analysis, from ἀνὰ, thoroughly, and λύω, to loosen; the separation of a whole into parts.

Angle, from *angulus*, a corner; the inclination of two straight lines to each other, which meet together, but are not in the same straight line.

Anhydrous, from ἀ, not, and ὕδωρ, water; containing no water.

Anion, from ἀνὰ, up, and εἶμι, to go; that which goes up; a substance which in electrolysis, passes to the Anode.

Anode, from ἀνὰ, up, and ὁδὸς, a way; the way which the sun rises; the surface at which the electricity passes into a body, supposing the currents to move in the apparent direction of the sun.

Anomaly, -**lous**, from ἀ, not, and νόμος, a law; an irregularity or deviation from a law.

Antagonism, from ἀντὶ, against, and ἀγωνίζομαι, to contend; opposition of action.

Antagonist, one who contends against another.

Anti-septic, from ἀντὶ, against, and σήπω, to make rotten; possessing the power of preventing putrefaction.

Approximate, -**ively**, from *ad*, to, and *proximus*, nearest; having affinity with; bordering upon.

Aqua Regia, i. e. **Regal Water**, a mixture of nitric and muriatic acids; so called from its property of dissolving gold, held by the alchemists to be *the king of the metals*.

Aqueo, from *aqua*, water; when prefixed to a word, denotes that water enters into the composition of the substance which it signifies.

Arc, from *arcus*, a bow; a part of a curved line, as of a circle, ellipse, &c.

Armature, from *armo*, to arm; a piece of soft iron applied to a load-stone, or connecting the poles of a horse-shoe magnet.

Astatic Needle, from ἄστατος, balanced; a double magnetic needle, not affected by the earth's magnetism.

Astronomy, from ἄστρον, a star, and νόμος, a law or rule; the science, which treats of the heavenly bodies, their motions, periods, &c., and the causes on which they depend.

Athermanous, from ἀ, not, and θέρμος, heat; that, through which heat will not pass, is said to be Athermanous.

Atmosphere, -**ic**, from ἀτμὸς, vapour, and σφαῖρα, a sphere; the sphere of air. which surrounds the globe.

Atom, -**ic**, from ἀ, not, and τέμνω, to cut; a minute particle not susceptible of further division.

Attraction, -**ive**, from *ad*, to, and *traho*, to draw; the tendency which bodies have to approach each other.

Austral, from *auster*, the south; southern.

Axis, in geometry, the straight line in a plane figure, about which it revolves to produce or generate a solid: more generally the right line conceived to be drawn from the vertex of a figure to the middle of the base.

Azote, from ἀ, not, and ζωή, life; another name for nitrogen, (which see.) It is so called because it will not support respiration.

Barium, from βαρὺς, heavy; a metallic substance of dark gray colour, hitherto produced in very small quantities from Baryta.

BAROMETER, -RICAL, from *βάρος*, weight, and *μέτρον*, a measure; an instrument for measuring the varying weight of the atmosphere.

BARYTA; a compound of oxygen, and Barium, possessing alkaline qualities.

BIBULOUS, from *bibo*, to drink; that which has the quality of drinking in moisture.

BIFURCATION, from *bis*, twice, and *furca*, a fork; a forking or division into two branches.

BINARY, from *bis*, twice; containing two units.

BINAXIAL, from *bis*, twice, and *axis*, an axis; having two axes.

BITUMEN, -MINOUS, from *bitumen*, pitch; the name given to several inflammable substances, which, though of vegetable origin, are found in the earth, or issue from the surface.

BOREAL, from *boreas*, the north; northern.

BORON; a dark, olive-coloured substance obtained from boracic acid, insoluble in water, and a non-conductor of electricity.

BROMINE, from *βρῶμος*, a strong odour; a liquid of a reddish-brown colour, which possesses a suffocating odour and pungent taste.

CALORIC, from *calor*, heat; an imaginary fluid substance, supposed to be diffused through all bodies, and the sensible effect of which is called heat.

CALORIFIC; imparting the sensation and other effects of heat.

CALORIMETER, from *calor*, heat, and *metrum*, a measure; an instrument for measuring caloric.

CAPILLARY, from *capillus*, a hair; resembling or having the form of hairs.

CAPSULE, from *capsula*, a little chest; a small shallow cup.

CARBON, from *carbo*, a coal; the chemical name for charcoal.

CATALYSIS, from *κατὰ*, thoroughly, and *λύω*, to loosen; an imaginary force which is supposed to assist the decomposition of some bodies, and the composition of others.

CATHODE, from *κατὰ*, downwards, and *ὁδὸς*, a way; the way which the sun sets; the surface at which electricity passes out of a body, supposing the current to move in the apparent direction of the sun.

CATION, from *κατὰ*, down, and *εἶμι*, to go; that which goes down; a substance which in electrolysis passes to the Cathode.

CAUSTIC, from *καίω*, to burn; possessing the power of burning.

CHEMISTRY, -ICAL, from an Arabic word, signifying the knowledge of the substance or constitution of bodies; the science, whose object it is to examine the constitution of bodies.

CHLORINE, from *χλωρὸς*, green; a yellowish-green coloured gas, of a pungent smell, and most injurious to respiration.

CIRCULATION; motion in a circle.

CIRCUMFERENCE, -TIAL, from *circum*, around, and *fero*, to bear; the line which is the boundary of a circle.

CLEAVAGE, PLANE OF; the plane in which crystals have a tendency to separate.

COERCIBLE, from *coerceo*, to restrain; susceptible of restraint.

COHESION, -IVE, from *cum*, together, and *hæreo*, to stick; the relation among the component parts of a body, by which they cling together.

COLANDER, from *colo*, to strain; a kind of strainer.

COMBUSTION, from *comburo*, to burn; the disengagement of light and heat which accompanies chemical combination.

COMPLEMENTARY, from *compleo*, to fill; that which is capable of filling up, so as to make the entire measure of, a quantity.

CONCAVE, from *concavus*, hollow; curved inwardly or hollow.

CONDUCTION, from *con*, together, and *duco*, to lead. The power of transmittin caloric without change in the relative position of the particles of the conducting body.

CONE, -ICAL, and -IC; a solid figure, having a circular base, and its other extremity or vertex terminated by a point.

CONGELATION, from *con*, together, and *gelo*, to freeze; the process of freezing.

CONGERIES, from *congeries*, a heap; a mass of bodies heaped up together.

CONSTITUENT, from *constituo*, to put together; that, of which any thing consists or is made up.

CONTACT, from *con*, together, and *tango*, to touch; the relative state of two things, which touch one another but do not cut.

CONTRACTION, from *con*, together, and *traho*, to draw; the state of being drawn into a narrow compass.

CONVERGENT, from *con*, together, and *vergo*, to bend; tending to one point from various parts.

CONVECTION, from *con*, together, and *veho*, to carry; the power in fluids of transmitting heat or electricity by currents.

CONVEX, from *con*, together, and *veho*, to carry; curved outwardly, or protuberant.

CORPUSCULAR, from *corpus*, a body; composed of, or relating to atoms.

CORUSCATION, from *corusco*, to flash or shine; a flash, or quick vibration of light.

CRUCIBLE, from *crux*, *crucis*, a cross; a little pot such as goldsmiths melt their gold in; so called from having a cross impressed upon it.

CRYOPHORUS, from κρύος, cold, and φέρω, to produce; an instrument for showing the relation between evaporation at low temperatures and the production of cold.

CRYSTALLOGRAPHY, from κρύσταλλος, a crystal, and γράφω, to describe; the science which treats of crystals.

CRYSTALS, -LINE, from κρύσταλλος, ice; a substance having a regular form, as rock crystal which resembles ice.

CRYSTALLIZATION; the formation of crystals during the passage of certain bodies from a fluid to a solid form.

CUBE, -IC; a solid figure contained by six equal squares.

CYANOGEN, from κύανος, blue, and γεννάω, to produce; a colourless gas, which burns with a peculiar purple flame; it is the essential ingredient in the pigment called "Prussian blue."

Cyanuret or **Cyanide**; the compounds of Cyanogen, which are not acid.

Cylinder, -rical; a solid figure described by the revolution of a right-angled parallelogram, about one of its sides which remains fixed.

Decomposition; the resolution of a compound body into its component parts.

Decrement, from *decresco*, to grow less; the quantity by which anything decreases or becomes less.

Deduction, from *de*, down, and *duco*, to lead; the process of reasoning by which we infer particular from general truths.

Deflagration, from *deflagro*, to burn; burning.

Deflection, from *de*, from, and *flecto*, to bend; a turning aside out of the straight way.

Degree, from *de*, down, and *gradus*, a step; a quantity in measurement, as, in geometry, the 360th part of the circumference of a circle.

Deliquescence, from *deliqueo*, to melt; a gradual melting, caused by the absorption of water from the atmosphere.

Density, from *densus*, thick; vicinity or closeness of particles.

Dephlogisticated; deprived of phlogiston, the supposed principle of inflammability.

Detonation, from *detono*, to thunder; explosion, accompanied with noise.

Diagram, from *διαγράφω*, to delineate; a delineation or representation of geometrical and other figures.

Diameter, from *διὰ*, through, and *μέτρον*, a measure; the line which passes through the centre of a circle, or of any other curvilinear figure.

Diaphanous, from *διὰ*, through, and *φαίνω*, to shine; that which allows a passage to the rays of light.

Diaphragm, from *διὰ*, division, and *φράσσω*, to shut up; a separation between two things.

Diathermanous, from *διὰ*, through, and *θέρμος*, heat; that through which heat will pass is said to be diathermanous.

Dielectric, from *διὰ*, through, and *ἤλεκτρον*, electricity; a substance through which electricity may be transmitted.

Diffraction, from *dis*, signifying division, and *frango*, to break; the deviation of rays of light from their straight course, when made to pass by the boundaries of an opaque body.

Dilatation, from *differro*, to bear apart; the act of extending into greater space.

Dimorphous, from *δὶς*, twice, and *μορφὴ*, a form; having two forms.

Disc, from *discus*, a quoit; the apparent surface of a heavenly body.

Disintegration, from *dis*, meaning separation, and *integer*, whole; an utter separation of particles.

Dispersion, -ive, from *di*, in different directions, and *spargo*, to scatter; the act of scattering.

Disruption, from *dis*, in different directions, and *rumpo*, to break; the act of tearing asunder.

Dissection, from *disseco*, to cut to pieces; the act of separating into pieces.

Distillation, separation drop by drop; the process by which a fluid is separated from another substance, by first being converted into vapour, and afterwards condensed drop by drop.

Divellent, from *divello*, to tear asunder; that which causes separation.

Divergent, from *di*, in different directions, and *vergo*, to bend; tending to various parts from one point.

Dodecahedron, from *δώδεκα*, twelve, and *ἕδρα*, a base, or side; a solid figure contained by twelve equal sides.

Dynamics, -ical, from *δύναμις*, power; that branch of mechanical science, which treats of moving powers, and of the action of forces on solid bodies, when the result of that action is motion.

Ebullition, from *ebullio*, to boil; the act of boiling.

Educt, from *e*, out of, and *duco*, to draw; any thing separated from another with which it previously existed in combination.

Efflorescence, from *effloresco*, to blow as a flower; the formation of small crystals on the surfaces of bodies, in consequence of the abstraction of moisture from them by the atmosphere.

Elasticity, -ic, from *ἐλαύνω*, to push or thrust; the property bodies possess of resuming their original form, when pressure is removed.

Electricity, from *ἤλεκτρον*, amber; the name of a power of matter, which produces a variety of peculiar phenomena, the first of which were observed in the mineral substance called amber; the laws, hypothesis, and experiments by which they are explained and illustrated, constitute the science of electricity.

Electrode, from *ἤλεκτρον*, electricity; and *ὁδός*, a way; the point at which an electric current enters or quits the body through which it passes.

Electrolysis, -lyte, &c., from *ἤλεκτρον*, electricity, and *λύω*, to loosen; the act of decomposing bodies by electricity.

Electro-magnetism; magnetism produced by electricity.

Electrometer; an instrument for ascertaining the quality and quantity of electricity in electrified bodies.

Electrophorus; an instrument for producing electricity.

Electroscope; an instrument for exhibiting the attractive and repulsive agencies of electricity.

Element, -ary, from *elementum*, an element; that which cannot be resolved into two or more parts, and contains but one kind of ponderable matter.

Ellipse, from *ἐκ*, deficiently, and *λείπω*, to leave; one of the conic sections formed by the intersection of a plane and a cone, when the plane makes a less angle with the base than that formed by the base and the side of the cone.

Emanation, from *e*, out, and *mano*, to flow; that which issues from any substance or body.

Empirical, from ἐν, in, and *πειράομαι*, to make trial; that which is made, or is done, as an experiment, independently of hypothesis or theory.

Empyreumatic, from ἐν, in, and πῦρ, fire; having the taste or smell of burnt animal or vegetable substances.

Endosmose, from ἔνδον, within, and ὠσμὸς, the act of pushing; a flowing from the outside to the inside.

Epidermis, from ἐπὶ, upon, and δέρμα, the skin; the exterior layer of the skin.

Equator, from *æquus*, equal; a great circle of the sphere, equally distant from the two poles; when the sun is in this circle, the days and nights are equal in all parts of the world.

Equilibrium, from *æquus*, equal, and *libra*, a balance: the state of rest produced by forces equally balancing one another.

Equivalent, from *æquus*, equal, and *valeo*, to be worth; equal in value.

Etiolation; the blanching of vegetables by exclusion from light.

Evaporation, from *e*, out, and *vapor*, vapour; the conversion of a liquid into vapour.

Exosmose, from ἔξω, without, and ὠσμὸς, the act of pushing; a flowing from inside to the outside.

Expansion, from *expando*, to open out; the enlargement or increase in the bulk of bodies, which is produced by heat.

Experience, from *experior*, to attempt, to try; knowledge gained by observation.

Experiment; something done in order to discover an uncertain or unknown effect.

Explosion, from *ex*, out, and *plaudo*, to utter a sound; a sudden expansion of an elastic fluid with force, and a loud report.

Extraneous, from *extra*, without; foreign and contrary to the nature of a thing.

Felly; the exterior rim of a wheel, supported by the spokes.

Ferruginous, from *ferrum*, iron; of iron.

Filter; a strainer.

Filtration; the process whereby liquids are strained.

Flexure, from *flecto*, to bend; the act of bending; also the bend or curve of a line or figure.

Fluorine, from *fluo*, to flow; an elementary principle of fluor-spar, which is so called from its acting as a flux in the working of minerals.

Focus, **-cal**, from *focus*, a fire-place; a point, in which a number of rays of light or heat meet after being refracted or reflected.

Formula, a general theorem; it is called Algebraic, Logarithmic, &c., according to the branch of mathematics to which it relates.

Friction, from *frico*, to rub; the rubbing or grating of the surfaces of bodies upon one another; also the retarding force caused by this rubbing of surfaces together.

Galvanism, from Professor Galvani; current electricity is sometimes so called.

Galvanometer; an instrument for measuring galvanism.

Gas, -eous; a term first introduced by Van Helmont; a permanent aëriform fluid.

Gelatinous, from *gelo*, to freeze; resembling jelly.

Goniometer, from γωνία, an angle, and μέτρον, a measure; an instrument for measuring angles.

Genus, -eric, from *genus*, a whole race or kind.

Geometry, -ical, from γῆ, the earth, and μέτρον, a measure; the science which treats of the relative magnitudes of extended bodies.

Gravitation, from *gravis*, heavy; the abstract power which draws bodies towards each other's centres.

Gravity, from *gravis*, heavy; the natural tendency of bodies to fall towards a centre.

Gravity, Specific; the relative gravity of a body, considered with regard to some other body, which is assumed as a standard of comparison.

Halo, from ἅλως, a crown; a luminous circle, appearing occasionally around the heavenly bodies; but more especially about the sun and moon.

Heliographic, from ἥλιος, the sun, and γράφω, to write; delineated by the sun.

Helix, from ἑλίσσω, to twist round; a screw, or spiral.

Hemisphere, from ἥμισυς, half, and σφαῖρα, a sphere; the half of a sphere formed by a plane passing through the centre.

Hermetic Seal; when the neck of a glass vessel or tube is heated to the melting point, and then twisted with pincers until it be air-tight, the vessel, or tube, is said to be hermetically sealed, or to have received the seal of Hermes, the reputed inventor of chemistry.

Heterogeneous, from ἕτερος, different, and γένος, kind; different in nature and properties.

Homogeneous, from ὁμὸς, alike, and γένος, kind; alike in nature and properties.

Horizontal, from ὁρίζω, to bound, or terminate; parallel to the horizon.

Hydrate, from ὕδωρ, water; any uncrystallized substance which contains water in a fixed definite proportion.

Hydrogen, from ὕδωρ, water, and γεννάω, to produce; an inflammable, colourless and aëriform fluid; the lightest of all known substances, and one of the elements of water.

Hydro; when prefixed to the name of a chemical substance, denotes that hydrogen enters into the composition of the substance which it signifies.

Hydrometer, from ὕδωρ, water, and μέτρον, a measure; an instrument for comparing the density and gravity of liquids with water.

Hydrostatics, from ὕδωρ, water, and στατὸς, standing; that branch of Natural Philosophy, which treats of the pressure and equilibrium of non-elastic fluids, and also of the weight, pressure, &c., of solids immersed in them.

Hygrometer, from ὑγρὸς, moist, and μέτρον, a measure; an instrument for ascertaining accurately the quantity of moisture in the atmosphere.

Hygroscope, from ὑγρὸς, moist, and σκοπέω, to consider; an instrument for exhibiting approximatively the moisture of the atmosphere.

Hyperbola, from ὑπὲρ, excessively, and βάλλω, to place; one of the conic sections formed by the intersection of a plane and a cone, when the plane makes a greater angle with the base of the cone than that formed by the base and the side of the cone.

Hypo, from ὑπὸ, under; when prefixed to a word, denotes an inferior quantity of some ingredient which enters into the composition of the substance which it signifies.

Hypothesis, -tical, from ὑπὸ, under, and τίθημι, to place; a principle supposed or taken for granted in order to prove a point in question.

Immediately, from *im*, without, and *medius*, intervening; without the intervention of a second cause.

Impinging, from *impingo*, to strike against; dashing against.

Incandescent, from *incandesco*, to grow white; white or glowing with heat.

Incidence, from *in*, upon, and *cado*, to fall; the direction, in which one body falls on or strikes another; the angle, which the moving body makes with the plane of the body struck, is called the "angle of Incidence."

Increment, from *incresco*, to increase; the quantity by which anything increases or becomes greater.

Induction, -ive, from *in*, to, and *duco*, to lead; the process of reasoning, by which we are led from general to particular truths.

Induction, Electrical; the effect produced by the tendency of an insulated electrified body to excite an opposite electric state in neighbouring bodies.

Inductometer; an instrument for measuring Electrical Induction.

Inertia, from *inertia*, inactivity; the disposition of matter to remain in its state of rest or motion.

Inflammable, from *in*, and *flamma*, a flame; capable of burning with a flame.

Inflection, from *in*, to, and *flecto*, to bend; the same as Diffraction; which see.

Insulation, from *insula*, an island; when a body, containing a quantity of free heat, or of electricity, is surrounded by non-conductors, it is said to be *insulated*.

Integrant, from *integer*, whole, entire; those parts of a body which are of the same nature with the whole, are called Integrant.

Interstices, from *interstitium*, a break or interval; the unoccupied spaces between the molecules of bodies.

Iodide; from ἴον, a violet, and εἶδος, the form or likeness; a compound of Iodine which is not used.

Iodine; a soft opaque substance of a blueish-black colour; when heated it gives off a violet-coloured gas.

Iridescent, from *Iris*, the rainbow; marked with the colours of the rainbow, ISOCHRONOUS, from ἴσος, equal, and χρόνος, time; performed in equal times.

ISOMERIC, from ἴσος, equal, and μέρος, a part; substances, which consist of the same ingredients, in the same proportion, and yet differ essentially in their properties, are called Isomeric.

ISOMERISM; that portion of Chemical Science which treats of Isomeric substances.

JUXTA-POSITION, from *juxta*, near, and *pono*, to place; the placing of one thing close to another.

LAMINÆ, from *lamina*, a thin plate; extremely thin plates, of which some solid bodies are composed.

LENS, from *lens*, a bean; properly a small glass in the form of a bean; but more generally it means a piece of glass, or other transparent substance, having its two surfaces so formed that the rays of light, in passing through it, have their direction changed, and are made to diverge or converge, or to become parallel after diverging or converging.

LEVIGATION, from *lævis*, smooth; the art of reducing to a light powder.

LIGNIN, from *lignum*, wood; the fibrous structure of vegetable bodies, which remains when all the substances which are soluble have been removed.

LIQUEFACTION, from *liquefacio*, to make liquid; the process of converting into a liquid state.

LITMUS; a blue pigment obtained from the *Lichen rocella;* it is a most delicate test of acids, which turn it red.

LOADSTONE, i. e. LEADSTONE; an ore of iron having magnetic properties.

LOGOMETRIC, from λόγος, a proportion, and μέτρον, measure; measuring proportionate spaces.

MAGNET, from *Magnesia*, a town in Asia Minor; artificial magnets are small bars of steel or iron, which, when placed at liberty, turn one end to the north.

MAGNETISM; the peculiar property possessed by certain ferruginous bodies, whereby, under certain circumstances, they attract and repel one another according to certain laws.

MAGNETO-ELECTRICITY; electricity produced by magnetism.

MALLEABLE, from *malleus*, a hammer; that which is capable of being spread by beating.

MANUFACTURE, from *manus*, the hand, and *facio*, to make; literally, anything made by the hand.

MASS, -IVE; the quantity of matter in a body which is in proportion to the weight.

MATHEMATICS, -AL, from μανθάνω, to learn; the science which treats of the ratios of numbers and quantities.

MAXIMUM, from *maximus*, greatest; the greatest value of a variable quantity.

Mechanics, from *μηχανή*, a machine; the science which treats of the laws of the rest and motion of bodies.

Mediately, from *medius*, intervening; with the intervention of a second cause.

Meridian, from *meridies*, mid-day; the *Terrestrial meridian* of a station on the earth's surface, is the great circle passing through both the poles of the earth, and through the place.

Metallurgy, from *μέταλλον*, a metal, and *ἔργον*, a work; the art of working metals and separating them from their ores.

Metaphysics, -ical, from *μετὰ*, beyond, and *φύσις*, nature; the science which treats of objects inaccessible to the senses.

Methylene, from *μέθυ*, wine; a compound resembling alcohol in its constitution.

Mineralogy; the science, which treats of bodies not being vegetable or animal.

Minimum, from *minimus*, least; the least value of a variable quantity.

Moirée Métallique, from *moirée*, a watered silk; when tin plates are washed over with a weak acid, the crystalline texture of the tin becomes apparent, forming a crystalline appearance, which has been called Moirée Métallique.

Molecules, -ar, a diminutive from *moles*, a mass; the infinitely small material particles of which bodies are conceived to be aggregations.

Momentum, from *moveo*, to move; the product of the numbers which represent the quantity of matter and the velocity of a body, is called its momentum, or quantity of motion.

Mucilaginous; resembling mucilage or gum.

Multiple, from *multiplico*, to render manifold; a quantity is said to be a multiple of another, when it contains that other quantity a certain number of times without a remainder.

Nascent, from *nascor*, to be born; in the moment of formation.

Negative, from *nego*, to deny; quantities to which the sign of subtraction or negative sign is prefixed, are called negative quantities; this sign is also used to denote operations which are the reverse of those denoted by the positive sign.

Nitrogen, from *νίτρον*, nitre, and *γεννάω*, to produce; a colourless gas, devoid of taste or smell; it is one of the constituents of the atmosphere.

Nodes, -al, from *nodus*, a knot; in the doctrine of curves, a node is a small oval figure made by the intersection of one branch of a curve with another.

Normal, from *norma*, a rule; according to rule.

Nucleus, from *nucleus*, a kernel; the central parts of a body which are supposed to be firmer, and separated from the other parts, as the kernel of a nut is from the shell; also, the point about which matter is collected.

Oblate, from *ob*, in front of, and *latus*, broad; flattened, or shortened.

Oblong, from *ob*, in front of, and *longus*, long; greater in length than in breadth.

Octohedron, -al, from ὀκτὼ, eight, and ἕδρα, a side; a solid figure contained by eight equal and equilateral triangles.

Olefiant Gas, from *oleum*, oil, and *fio*, to become; a colourless, tasteless gas, which derives its name from its property of forming an oil-like liquid with chlorine.

Optics, from ὄπτομαι, to see; that branch of Natural Philosophy which treats of vision, and of the nature and properties of light, and of the various changes it undergoes.

Organic Matter, from ὄργανον, an organ; when matter possesses organs, or organized parts for sustaining living action, as animals and plants, it is called organic.

Organization; construction in which the parts are so disposed as to be subservient to each other.

Oscillation, from *oscillor*, to swing; the vibration, or reciprocal ascent and descent of a pendulum.

Oxide; a combination with oxygen, not being acid.

Oxidizable; capable of being converted into an oxide.

Oxygen, from ὀξὺς, acid, and γεννάω, to produce; a colourless, aëriform fluid, which was formerly supposed to be the universal acidifying principle.

Parabola, from παρὰ, parallel to, and βάλλω, to place; one of the conic sections, formed by the intersection of a plane and a cone, when the plane passes parallel to the side of the cone.

Parallel; a term applied in geometry to lines and planes, which are everywhere equidistant from one another; straight lines, which, if infinitely produced, never meet, are called parallel straight lines.

Parallelogram; a four-sided figure, of which the opposite sides are parallel and equal.

Parallelopipedon; a solid figure contained by six parallelograms, the opposite sides of which are equal and parallel.

Pellicle, a diminutive from *pellis*, a skin, or crust; a thin crust formed on the surface of a solution by evaporization.

Pendulum, from *pendeo*, to hang; a heavy body so suspended, that it may vibrate or swing backwards and forwards about some fixed point, by the action of gravity.

Percolate, from *per*, through, and *colo*, to strain; to strain through.

Permeate, from *permeo*, to pass through; to penetrate.

Perpendicular; the straight line, which, standing upon another straight line, makes the adjacent angles equal and consequently right angles, is said to be perpendicular to the line upon which it stands.

Phenomenon, from φαίνομαι, to appear; an appearance.

Philosophy, -ical, from φιλέω, to love, and σοφία, wisdom; the study or knowledge of nature, or morality, founded on reason and experience, the word originally implying "A love of wisdom."

Phlogiston, from φλέγω, to burn; a name given by the older chemists to an imaginary substance, which was considered as the principle of Inflammability.

PHOSGENE, from φῶς, light, and γεννάω, to produce; produced by light.

PHOSPHORUS, from φῶς, light, and φέρω, to produce; a highly inflammable substance, obtained from calcined bones, which emits light when placed in the dark.

PHOTOMETER, from φῶς, light, and μέτρον, a measure; an instrument for measuring the different intensities of light.

PHYSICS, -ICAL, from φύσις, nature; the science of natural bodies, their phenomena, causes, and effects, with their affections, motions, and operations.

PHYSIOLOGY, -ICAL, from φύσις, nature, and λόγος, an account; the science which treats of the structure of living beings.

PLUMMET, from *plumbum*, lead; a weight suspended from a string to mark the direction of gravity on a perpendicular to the earth.

PNEUMATICS, from πνεῦμα, air; that branch of Natural Philosophy, which treats of the weight, pressure, and elasticity of aëriform fluids.

POLARITY; the opposition of two equal forces in bodies, similar to that which confers the tendency of magnetized bodies to point to the magnetic poles.

POLARIZATION; the communication of the above opposition of forces.

POLARIZED LIGHT; light, which, by reflection or refraction at a certain angle, or by refraction in certain crystals, has acquired the property of exhibiting opposite effects in planes at right angles to each other, is said to be polarized.

POLES; the extremities of the axis about which a body revolves.

POLES OF A MAGNET; points in a magnet, where the intensity of the magnetic force is a maximum; one of these attracts, and another repels the same pole of another magnet.

PORES, from πόρος, a passage; the small interstices between the solid particles of bodies.

PRECIPITATION, from *præcipito*, to fall suddenly; the separation of a solid from a liquid; a triangular glass solid used for the separation of rays of light by refraction.

PRODUCT, from *pro*, forth, and *duco*, to draw; anything formed from the elements of another by an operation.

PROGRESSION, from *pro*, forwards, and *gradior*, to step; a series of quantities advancing in the same manner or according to the same law; in an arithmetic progression, they increase or decrease by a common difference; in a geometric by a common ratio.

PROJECTILE, from *pro*, forwards, and *jacio*, to throw; a heavy body projected, or cast forwards into space, by any external force.

PROPORTION; the relation of equality subsisting between two ratios.

PROTRACTOR, from *pro*, forwards, and *traho*, to draw; an instrument for protracting or laying down on paper the angles of a figure.

Pyrometer, from πῦρ, fire, and μέτρον, a measure; an instrument for measuring higher degrees of temperature than can be ascertained by a thermometer.

Pyroxylic Spirit, from πῦρ, fire, and ὀξύς, acid; a colourless transparent spirit obtained by the destructive distillation of wood.

Pyro; when prefixed to a word denotes that the substance which it signifies has been formed at a high temperature.

Quadrant; the fourth part of the circumference of a circle.

Qualitative; regarding the properties of a body without reference to quantity.

Quantitative; regarding quantities.

Radiation, from *radius*, a ray; the shooting forth in all directions from a centre.

Radical, from *radix*, a root; the original principle of a compound.

Radius; the straight line drawn from the centre to the circumference of a circle.

Rarefaction, from *rarus*, rare, and *facio*, to make; the act of causing a substance to become less dense; it also denominates the state of this lessened density.

Ratio; the relation which subsists between two quantities of the same kind, the comparison being made by considering what multiple part or parts one of them is of the other.

Ray; a beam of light propagated from a radiant point.

Reaction; the reciprocation of any impulse, or force impressed, made by the body on which such impression is made. Reaction is always equal to action.

Recondite, from *recondo*, to hide; hidden or concealed.

Rectangle, from *rectus*, right, and *angulus*, an angle; a four-sided plane figure, in which all the angles are right angles, and its opposite sides equal and parallel.

Rectification; the process of drawing anything off by distillation, in order to make it more pure and refined.

Rectilinear; consisting of, or bounded by straight lines.

Reflection, from *re*, back, and *flecto*, to bend; the act of bending back; when rays of light fall on the surfaces of bodies, part of them are thrown back or reflected.

Refraction, from *re*, back, and *frango*, to break; the deviation of rays of light from their direct course, when passing through media of different densities.

Refrangible; susceptible of refraction.

Refrigeration, from *re*, again, and *frigo*, to cool; the act of cooling.

Repulsion, from *re*, back, and *pello*, to drive; that property in certain bodies, whereby they mutually tend to recede and fly off from each other.

Retort, from *re*, back, and *torqueo*, to twist; a vessel with a bent neck, which is made use of in chemical operations.

Rhombus; a figure, which has all its sides equal, but its angles are not right angles.

Rhombohedron; a solid figure, whose sides are composed of rhombi.

Rhomboid; a figure, which has its opposite sides equal, but all its angles are not equal, neither are all its angles right angles.

Salifiable Bases, from *sal*, salt, and *fio*, to become; bodies capable of combining with acids to form salts.

Sapid, from *sapio*, to taste of; possessing the power of exciting the organs of taste.

Saturation, -ated, from *satur*, full; the solution of one body in another, until the receiving body can contain no more.

Scale, from *scala*, a ladder; an instrument, in which a line is divided into small and equal parts, and which is applied for the purpose of ascertaining the relative dimensions of other lengths not so divided.

Section, from *seco*, to cut; a cutting, or part separated from the whole.

Segment of a Circle; any portion cut off by a straight line.

Selenium, from σελήνη, the moon; an inflammable solid body, of a reddish-brown colour; it is tasteless, and possesses metallic lustre.

Sine; the straight line, drawn from one extremity of an arc, perpendicular to the radius, which passes through the other extremity.

Solution, from *solvo*, to loosen; in chemical language, any fluid, which contains another substance dissolved in, and intimately mixed with it.

Solvent; any substance which will dissolve another.

Specific, from *species*, a particular sort or kind; that which denominates any property which is not general, but is confined to an individual or species.

Spectrum; the coloured image formed on a white surface by rays of light passing through a hole, and being refracted by a glass prism.

Sphere; the solid figure formed by the rotation of a semicircle about its diameter.

Spheroid, -al; a solid figure, formed by the revolution of an ellipse about one of its axes; hence it is sometimes called an ellipsoid; the spheroid will be oblate or prolate, according as the revolution is performed about the minor or major axis of the ellipse.

Statics, -ical, from στατὸς, standing; that branch of mechanical science which treats of the equilibrium, pressure, weight, &c., of solid bodies when at rest.

Stratum, from *sterno*, to strew; a layer.

Symmetry, -ical, from σὺν, together, and μέτρον, a measure; conformity of measure.

Synthesis, from σὺν, together, and τίθημι, to place; the composition of a whole from its parts; in mathematics, the process of reasoning out new principles from those already established.

Sublimation, from *sublimis*, high; the act of raising into vapour by means of heat and condensing in the upper part of a vessel.

Sulphuret; a combination of a metal with sulphur.

Synchronous, from *σὺν*, together, and *χρόνος*, time; performed in the same time.

Tactile, from *tango*, to touch; of, or relating to, touch.

Tangent, -ial; the line, which touches a circle or any other curve, but does not cut it.

Tentative, from *tento*, to try; experimental.

Ternary, from *ter*, thrice; containing three units.

Tetrahedron, from *τέσσαρες*, four, and *ἕδρα*, a base, or side; a solid figure contained by four equal and equilateral triangles.

Theory, -etical, from *θεωρία*, a view; a collected view of all that is known on any subject into one.

Thermo-Electricity; electricity produced by heat.

Thermometer, from *θέρμος*, heat, and *μέτρον*, a measure; an instrument for measuring the degrees of heat.

Thermoscope, from *θέρμος*, heat, and *σκοπέω*, to view; an instrument for exhibiting the powers of heat.

Tire; a hoop of iron, used to bend and receive the felly of a wheel.

Torsion, Force of, from *torqueo*, to twist; a term applied by Coulomb to denote the effort made by a thread, which has been twisted, to untwist itself.

Transparent; a term to denote the quality of a substance which not only admits the passage of light, but also of the vision of external objects.

Triturated, from *trituro*, to thrash; reduced to powder.

Truncation, from *truncus*, cut short; the cutting off a portion of a solid, as of the solid angle of a crystal.

Undulation, from *unda*, a wave; a formation of waves.

Uniaxal, from *unus*, one, and *axis*, an axis; having but one axis.

Vacuum, Latin; a space empty and devoid of all matter.

Ventilation, from *ventus*, wind; the supply of fresh air.

Vernier; an instrument invented by Vernier; it consists of a small movable scale, running parallel to the fixed scale of a quadrant, or other instrument, and having the effect of subdividing the divisions of the instrument into more minute parts.

Vibration, from *vibro*, to brandish; the regular reciprocating motion of a body, as of a pendulum, &c.; a motion to and fro.

Volume, from *volumen*, a roll; the apparent space occupied by a body.

Weight; the pressure which a body exerts vertically downwards, in consequence of the action of gravity.

Zero; the numeral 0, which fills the blank between the ascending and descending numbers in a series.

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